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Development of GreenDealz: A public engagement toolkit addressing critical raw materials and the EU Green Deal at informal education settings

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Abstract. One of the most important challenges that Europe faces to date is the need for a sharp increase in the extraction, production and recycling of critical raw materials to meet the demands of renewable energy technologies as specified in the European Union's (EU) climate targets. However, this topic is not widely discussed amongst publics and is underrepresented within the field of informal public engagement. We present the development of a public engagement toolkit called 'GreenDealz' that addresses this gap. We focus specifically on informal learning within the festival environment. GreenDealz was created via an iterative process informed by festival-based data collection and audience input. GreenDealz engages incidental audiences with a supermarket experience, where critical raw materials must be shopped for to build key renewable energy technologies and achieve EU climate goals. Evaluation is streamlined into the tactile experience of GreenDealz, employing embedded assessment measures which yield quantitative data that indicate this activity significantly enhances audience knowledge of this topic.

1. Introduction

1.1 Public engagement with critical raw materials and the European Union Green Deal

The European Union's (EU) Green Deal is the primary strategy that sets out the legally binding climate goals of the EU member states. The two main goals are (i) to have 55% less greenhouse gas emissions by 2030 and (ii) to be climate neutral by 2050 (European Commission, 2019). One of the key pathways to achieving these targets is the scaling up of renewable energy technologies and electrification as fossil fuels are phased out. However, the increase in renewable energy and battery/electrical power implies a steep increase in the demand for critical raw materials (CRMs) (Calvo and Valero, 2022; Vidal et al., 2013). CRMs refer to the many metals and minerals that are mined from the Earth (e.g., copper, cobalt, lithium) that are important for society and the green economy and have significant supply risk (European Commission., 2023; European Parliment and Council of the European Union, 2024). While recycling will be an increasingly important source of CRMs, it is

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

not expected to keep up with growing global CRM demands (Troll and Arndt, 2022; Vidal et al., 2013). Through the Critical Raw Materials Act, the EU will increase domestic CRM extraction, production and recycling rates by 2030 to at least 10%, 40% and 25% of European annual consumption respectively (Critical Raw Materials Act, European Parliment and Council of the European Union, 2024). To achieve these aims, substantial social, environmental and technical challenges need to be overcome. In general, the levels of social acceptance to mining projects are often relatively low due to distrust between publics and mining corporations, stemming largely from legacies of environmental degradation (Moffat and Zhang, 2014). Conversely, as suggested by Troll and Arndt (2022), the ever-increasing demand for CRMs for the green transition and notably, the digital economy, is potentially causing society to "turn a blind eye" to poor environmental and/or working regulations in mines outside of Europe, thus presenting an ethical dilemma (Sovacool et al., 2020). Moreover, there is there is limited public discussion around the need for CRMs to transition to a decarbonised economy (Richter et al., 2018; Rogers et al., 2024; Stewart, 2023), despite 2023 evidence that suggests that 87% and 86% of adult EU citizens believe the EU should take greater action to increase renewable energy and enhance energy efficiency respectively (European Commission and Directorate-General for Climate Action, 2023). Thus, the aim of this paper is to investigate how public engagement (PE) with CRMs and the green transition can be enhanced.

PE can be described as a flow or exchange of information between specialists/practitioners (e.g., scientists or science communicators) and publics to help enhance awareness about any given topic and/or increase public participation in research or decision making (Rowe and Frewer, 2005). PE allows meaningful engagement with publics on many societally relevant topics through free-flowing dialogue and listening (Pidgeon and Fischhoff, 2011). There have been some PE efforts aimed at raising public awareness about CRMs, their supply chains and uses in society or the circular economy (e.g., BGS Press, 2023; Richter et al., 2018; Whalen, 2013), some of which target children and teenagers (e.g., Baek et al., 2020). However, in the context of the green transition, most PE efforts have been focused on engaging audiences with sustainable energy science and practices (e.g., Benitz and Yang, 2020; Jellema and Mulder, 2016; Manzella et al., 2018; Parkins et al., 2018). With the 2030 and 2050 targets of the EU Green Deal nearing, it is important to stimulate the public debate about the need for CRMs to meet the EUs decarbonisation targets. In this paper we describe the development and testing of a PE toolkit known as 'GreenDealz' that engages audiences at informal education settings with CRMs and green energy.

1.2 Public engagement as a form of informal education: impact and evaluation

Of particular importance in engagement with geoscience is the need for the creation of PE content and experiences that are relevant, meaningful, and focused on the expectations and profile of the target group (Ford, 2019). This is especially the case when learning is not defined by an assumed knowledge deficit of the audience but rather as an open dialogue (Rodrigues et al., 2023). Informal education refers to the unexpected learning that audiences might experience through PE engagement activities, for example when related to leisure or daily life (Stocklmayer and Rennie, 2017). Informal learning can arise from an array of different PE activities and events. Popular settings for informal PE activities are festivals. Festivals (e.g., art,

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

cultural or science based) offer dynamic environments to engage incidental audiences with research, academic or technical concepts in a fun and casual manner (Sardo and Grand, 2016). The relaxed and informal nature of the festival environment offers an excellent stage on which to develop a PE experience that addresses the need to engage audiences with CRMs for the green transition, where publics may learn about this important EU challenge but in a digestible way. Previous research at informal PE events such as art, science or cultural festivals has shown that when engaging with science concepts, audiences value high levels of interactivity, hands-on participation and relaxed conversations with experts/scientists (Bultitude and Sardo, 2012; Jensen and Buckley, 2014; Roche et al., 2016a; Sardo and Grand, 2016). For a PE experience to be impactful, especially in the fast-paced and time-restrictive setting of a festival, the interaction needs to consume as little of the audience's time as possible, all while being attractive to festival goers, informative, stimulating and fun (Bultitude and Sardo, 2012; Grand and Sardo, 2017; Sardo and Grand, 2016; Vergunst et al., 2024).

The creation of effective PE toolkits are best achieved through systematic, formative and summative evaluation (Abrahamse, 2016), whilst also being suitable for the engagement style and format of the PE event. Many festival-based PE experiences with science and research have successfully involved traditional evaluation approaches such as surveys or questionnaires at pre and post stages or simply as a post-engagement assessment (Başaran and Topal, 2022; Jensen et al., 2021; Jensen and Buckley, 2014; Martin et al., 2022; Rose et al., 2017; Williams and Bowdin, 2007). However, self-reported or 'subjective' evaluation measures such as the Likert-type scales have been criticised as being ineffective for assessing knowledge or learning during a PE interaction (Jensen, 2014), whereby audiences may display subjective biases in their responses such as social desirability or evaluation apprehension bias (Grimm, 2010; Nederhof, 1985; Rosenberg et al., 1969), i.e., they may simply tell practitioners what they want to hear (Jensen, 2014). It has been suggested that traditional evaluation approaches or classroom type assessments are not suitable for incidental footfall events and that assessment within the informal environment should not disrupt the natural flow of an engagement (e.g., Becker-Klein et al., 2016; Grand and Sardo, 2017; Schweingruber and Fenichel, 2010), and thus it may be preferable to integrate the evaluation or assessments into the PE activity itself. This can include simple observations or short form interviews or casual discussions with participants (Grand and Sardo, 2017; Sardo and Grand, 2016). Indeed, for festivals, some authors highlight the high engagement value of evaluation tools such as live mobile-phone polling (e.g., Roche et al., 2016a, 2016b), 'graffiti walls' and suggestion boxes (e.g., (Archer et al., 2021; Grand and Sardo, 2017), or techniques such as brainstorming and idea mapping (Varner, 2014). In line with this, 'embedded assessment' has been suggested as a suitable alternative for measuring learning compared to classic survey or test-based evaluation, wherein activities that closely match the learning tasks of an engagement can act as assessment tools (Schweingruber and Fenichel, 2010). Thus, embedded assessment approaches act as 'authentic' forms of evaluation, specific to the PE interaction at hand, and have proven successful in measuring learning in both informal and formal science education settings (e.g., (Becker-Klein et al., 2016; Wilson and Sloane, 2000).

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

1.3 Aim of the paper

The overall aim of this paper is to design, create and evaluate a PE toolkit that enhances public engagement with CRMs and stimulates thinking about how CRMs are related to the EU Green Deal's targets. The objective of our toolkit is threefold. The first objective is to ensure that the target group will voluntarily start and continue to engage in the PE activity. Considering our interest in developing PE activities in festival settings, we aimed to create an experience that was eye-catching, stimulating and attractive to incidental audiences and ultimately an interaction that would ensure that our target group would engage enough to meet our second objective. The second objective is to ensure that informal learning takes place in our target group, specifically to increase their knowledge about the link between CRMs and decarbonisation. The final objective is to design an evaluation strategy that is 'festival-friendly', i.e., concise for the audience while capturing sufficient information to assess the effectiveness of the PE activity. Thus, we consider a PE 'toolkit' as representing the whole package of a festival PE experience; a PE activity or interaction designed to engage and inform a target group, and a 'festival-friendly' evaluation process. To achieve this, we set up an iterative process that included a scoping, testing, and refinement phase.

2. Development of the toolkit

2.1 Overview

Our process of iterative phases (Fig. 1) highlights the systematic approach to developing a PE toolkit that works for the festival setting, whereby each new iteration across the three phases, was built off the last until a final PE toolkit was developed. Thus, we report this development as methods and results collectively. We predominantly used festivals for data collection, as this provided real-world feedback and testing conditions. The scientific information behind the PE toolkit (e.g., CRM data) was collated from European Union reports, studies and databases or literature addressing CRMs and green/strategic technologies (Bobba et al., 2020; Calvo and Valero, 2022; Carrara et al., 2023, 2020; European Commission - Raw Materials Information System, 2023; European Commission, 2023; Troll and Arndt, 2022).

2.2. Analysis strategy

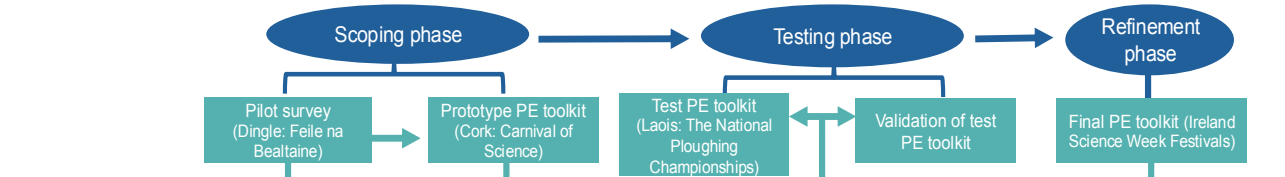
Qualitative and quantitative research methods were used to evaluate the effectiveness of the PE toolkit. For the quantitative analysis, data reduction and cleaning (e.g., scoring, coding and collating) was carried out in Microsoft excel. New and pre-existing scales were used as survey items, when appropriate with reverse scoring. The reliability of scales was conventionally analysed according to Cronbach's alpha (Cronbach, 1951). All statistical analyses were carried out in SPSS Statistics (version 29.0.0.0 (241)). Before each statistical test, data was assessed for key assumptions and when assumptions were violated, alternate or non-parametric tests were used. Where the assumption of normality was violated in scored survey responses, central tendency was given by median values rather than the mean. For the qualitative data (e.g., short feedback sections),

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

125 thematic analyses were carried out manually, by identifying re-occurring response themes and sub-themes and assigning codes (Braun and Clarke, 2006).

2.3. Participation and recruitment

For the data collection carried out at live events, sampling and recruitment was representative of and realistic to the free-flowing nature of the festival environment. Thus, convenience and snowball sampling were the primary methods used, as
130 participants often included those that were drawn to our exhibit(s). The only core sampling strategy devised ahead of each event was to achieve a maximum possible sample size, with a minimum sample size also in mind. These ideal sample sizes were based on the estimated interaction time per participant(s) (e.g., 10-15 minutes for the PE toolkit and 5-10 minutes to complete the surveys) calculated across the total time spent at an event.



PE toolkit name:		Shopping to Decarbonise	GreenDealz	GreenDealz
Evaluation style:	Paper survey	Paper survey (post activity)	Digital survey (pre and post "shopping")	Embedded assessment (pre and post "shopping")
Evaluation items:	Likert type & multiple choice	Likert type & multiple choice	Dichotomous tests & Likert scales	Scale items in-built within activity using blocks and weighing scales
Evaluated concepts:	Awareness, engagement desires & interest	Awareness, engagement desires & interest	**Exhibit & Validation:** Objective knowledge & perceived need for CRMs **Validation only:** subjective knowledge & environmental attitude	Objective knowledge
PE activity mechanics:		Shop for solar PV and wind energy (choose from 15 CRMs; up to 4 CRMs per technology). Estimation task about CRM demand. Results shown on paper.	Shop for solar PV and wind (choose from 10 CRMs, only allowed 3 CRMs for each technology) with import reliance integrated into shopping. Barcode scanning. Guessing task about CRM demand for 2050 climate goals using shopping scale. On-screen results and info.	Shop for solar PV and wind (choose from 10 CRMs, only allowed 3 CRMs for each technology) with import reliance integrated into shopping. Barcode scanning. On-screen results and info.
Activity scoring:		1 point per correct CRM	Points weighted to CRM prompt difficulty	Points weighted to CRM prompt difficulty
Time to complete:	10 minutes	20 minutes	10-15 minutes	~10 minutes

135

Figure 1: PE toolkit design and iteration process

In addition, we used more controlled settings to evaluate the toolkit, by using university student participants during the testing phase. They were recruited in class through an incentive-based approach, where a €100 price draw was held for all participants. Socio-demographic information was collected across all populations within each phase: gender, age, education level and place

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

of residence or nationality. It is important to remember that any given festival/event may attract certain age groups, genders, ethnicities or socioeconomic groups more than others which is difficult to avoid. Collection of all survey, assessment and activity (PE tool) data was consent-based. All participant answers were kept anonymous through unique identifiers or participant IDs. These IDs were used to link evaluation items and activity items. All participants were adults (18 years or over).

2.4. Scoping phase

The scoping phase represented the pilot research. The first aim of this phase was to probe two festival audiences on their comparative awareness and understanding of the topic of CRMs in connection to the EU Green Deal. The second aim was to gather feedback on audience engagement preferences to help inform the construction of a prototype PE toolkit (Fig. 1). This information was gathered via two pilot studies across two Irish festivals. The first pilot study was held at Feile na Bealtaine, Dingle, Co. Kerry, Ireland, an annual five-day arts and cultural festival in a rural location that celebrates the coming of Celtic summer via live performances, excursions and exhibitions. The second pilot study took place at the Cork Carnival of Science, an urban, science-focused, one-day festival based in Cork City, Ireland, that celebrates the wonder of science and technology in a field set-up with exhibitions, workshops and live performances.

2.4.1 Dingle Feile na Bealtaine festival: methods and results

An initial pilot survey was developed for use at Dingle and aimed to understand how best to develop a prototype PE toolkit. This pilot was conducted amongst 32 participants. The most common age bracket across the phase was 35-44 years and gender was evenly spread between male and female. There was an overrepresentation of university/college qualification (88%) and 44% were local to the province of the festival (Munster).

The survey included a 5-point Likert-type scale that consisted of two answering styles (A and B). This scale assessed broad awareness about CRMs and their links to the EU Green Deal (Table 1). Style A was answered as a ‘strongly disagree’ (1) to ‘strongly agree’ (5), while the style B was answered as ‘very unfamiliar’ (1) to ‘very familiar’ (5). These items were analysed as one variable to provide an overall ‘awareness’ score of the topic (Table 1), after concluding that the scale was reliable (α = 0.70). Responses indicated that the Dingle audience had a high self-reported awareness (4 ± 0.87; Table 1) about the topic, with the weaker points of awareness centred on the definition of critical raw materials and how exactly they link to the EU Green Deal (Table 1). The survey also included multiple choice and open-ended questions about audience interest, along with engagement preferences and feedback. When asked if they wanted to learn more about CRMs and the EU Green Deal, 56% of respondents said “yes” and 46% said “maybe”. In response to a multiple-choice question about engagement desires to learn more about the topic, the most popular responses across all age groups were ‘hands-on activities’ (76%) and ‘visual examples of CRMs’ (66%) (Fig. 2). This preference was echoed when we asked Dingle participants to elaborate on how they would like to learn, with most people expanding on the kinds of PE methodologies they would like to see, whereby a desire for interactivity

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

was the main sub-theme in respondent answers (Fig. 3). The next most popular answering style was related to the kind of content participants preferred, with most suggesting that they wanted to learn about the CRM supply chain or how CRMs link to their daily life (Fig. 3).

Table 1: Scoping phase pilot surveys addressing awareness of the topic (median ± median absolute deviation). †Indicates an item used at only one pilot event and therefore is not included in the comparative overall awareness score. *indicates where results between pilot events were significantly different ($p < 0.05$). From 1 to 5 on the Likert scale, items A1 to A4 followed the answering style of "strongly disagree" to "strongly agree", while items B1 to B2 followed the answering style of "very unfamiliar" to "very familiar". Overall 'awareness' scores were calculated as the sum of item medians/N items, where higher values indicate higher awareness.

Dingle survey items *(α = 0.70)*	Awareness Dingle	Cork survey items *(α = 0.64)*	Awareness Cork
A1: I have heard about critical raw materials†	3 ± 1	N/A.	N/A.
A4: I do not know what a critical raw material is	3 ± 1	A1: I did not know what a critical raw material was before this activity	3 ± 0.98
A2: Many critical raw materials used in society are mined from the earth	4 ± 0.56	A2: I knew that many critical raw materials used in society are mined from the earth	5 ± 0.69
A3: The EU is self-sufficient when it comes to raw material extraction & production	4 ± 0.64*	A3: I am surprised that the EU is not self-sufficient when it comes to raw material extraction & production	3 ± 1.2*
B1: How familiar are you with the use of critical raw materials in green energy & technology?	4 ± 1	B1: How familiar were you with the use of critical raw materials in green energy & technology before this event?	3 ± 1.1
B2: Are you familiar with the EU Green Deal & its connection to critical raw materials?	3 ± 1.1	B2: Were you familiar with the EU Green Deal & its link to critical raw materials before this event?	4 ± 1.3
Overall awareness Dingle:	***4 ± 0.87***	***Overall awareness Cork:***	***4 ± 1***

The preferences for interactivity, visual examples and relatability recorded via Dingle surveys, subsequently influenced the development of a prototype PE toolkit called 'Shopping to Decarbonise'; a hands-on, table-top activity that asked participants to 'shop' for key CRMs to build a solar panel and a wind-turbine (Fig. 1). For this task, a selection of 15 CRM cubes were displayed on top of a periodic table with CRMs highlighted (e.g., Fig. 4). These cubes contained visuals of CRMs (pure metals and ore samples), along with clues or prompts about their uses and properties to help participants load up their solar PV and wind-turbine 'shopping baskets'. Additional material (e.g., paper graphs, diagrams) were used to engage participants deeper in the topic (i.e., discussing import reliance levels and CRM demand to meet the EU Green Deal goals).

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

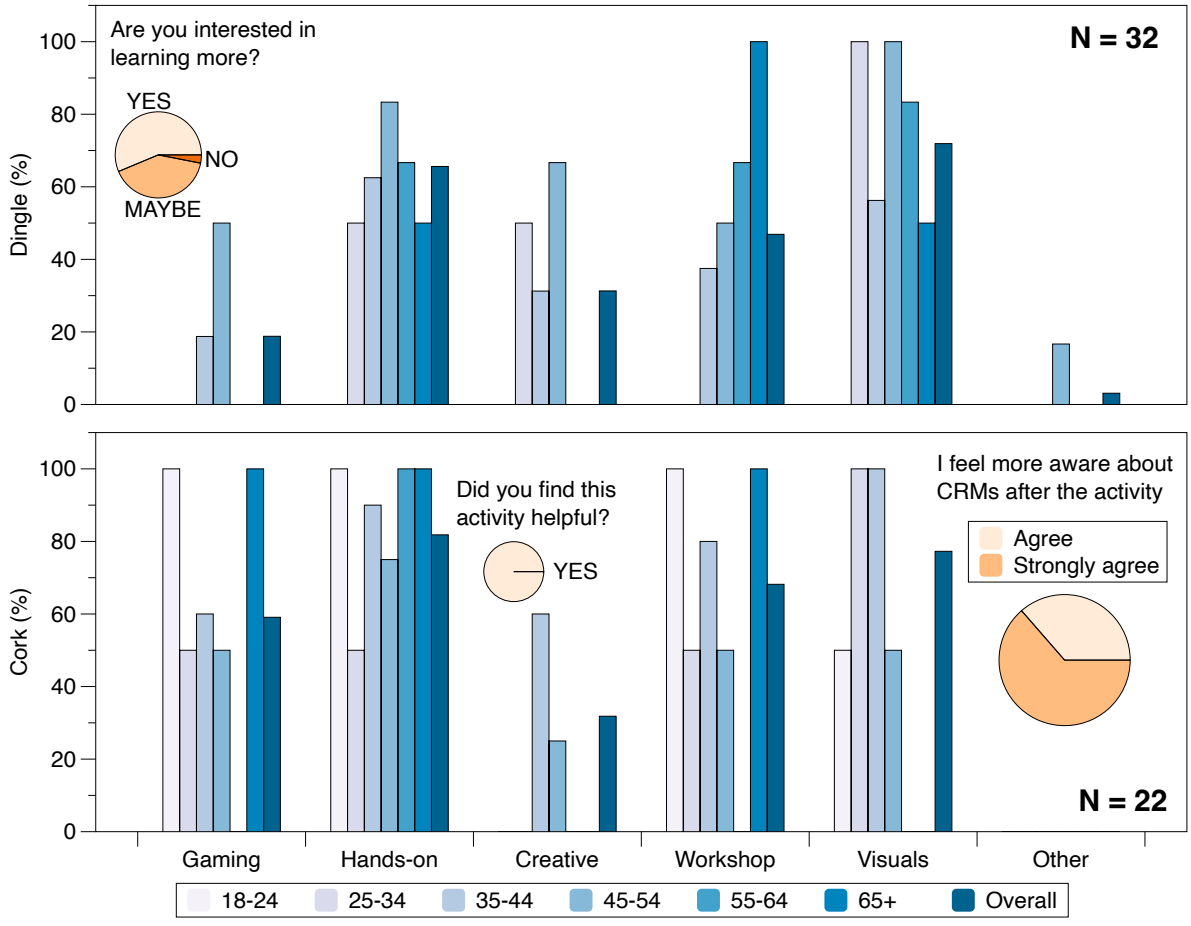


Figure 2: Scoping phase responses from Dingle (N = 32) and Cork (N = 22) audiences to preferred engagement preferences, subject interest and experience of prototype PE tool.

2.4.2. Cork Carnival of Science: methods and results

The prototype PE toolkit 'Shopping to Decarbonise' was displayed at an exhibition stand at Cork Carnival of Science, where 22 participants were attracted over of their own volition. The gender balance was 50% male and 50% female, with 46% of participants aged 35-44 years, 82% residing in Munster and 91% of university/college education. The evaluation component of the prototype PE toolkit 'Shopping to Decarbonise' included a post-activity survey that was an iteration of the Dingle survey, whereby the same or similar items/questions were asked of respondents but accounted for their knowledge before engaging with 'Shopping to Decarbonise' (Table 1).

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

The iteration of the awareness scale used in Cork appeared to have lower reliability than Dingle with $\alpha = 0.64$ (Table 1), perhaps due to the smaller sample size. However, as with Dingle, responses indicated that the audiences had high self-reported awareness (4 ± 1; Table 1) about the topic before engaging with Shopping to Decarbonise. Interestingly, in contrast to the Dingle sample, the Cork participants had a significantly lower self-reported awareness (mean rank = 20.39) about the levels of EU import reliance compared to Dingle (mean rank = 32.39) based on findings from a Mann Whitney U-test ($U = 195.5$, $Z = -2.854$, $p = 0.004$). This may be due to the comparatively greater live engagement with the high levels of EU import reliance in Cork via 'Shopping to Decarbonise', whereas Dingle participants were simply given a survey without any intervention. Hence, perhaps people overestimate their awareness of this topic in the absence of deeper PE through activities or tasks. However, this is said tentatively due to the relatively small sample sizes. Audience engagement preferences in Cork (via post-activity survey), were similar to Dingle, with 82% and 77% choosing hands-on activities and visual examples of CRMs respectively, although a greater proportion of people in Cork also preferred workshops (Fig. 2). All the Cork respondents said they found the prototype PE toolkit 'Shopping to Decarbonise' helpful, with 100% responding either 'strongly agree' or 'agree' to the statement: *I feel more aware about what a CRM is after this activity*. When asked for feedback on how to improve our PE toolkit, Cork respondents mostly expressed encouragement and a preference for interactivity/informal learning (Figs. 2-3).

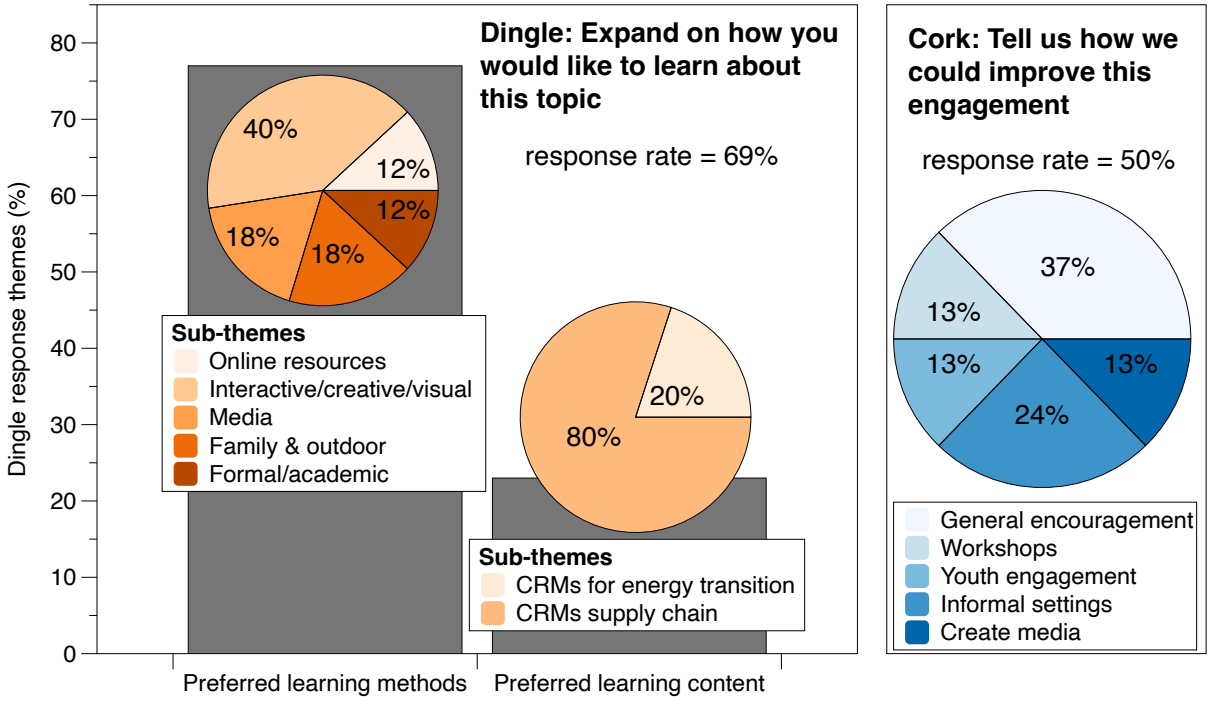


Figure 3: Qualitative responses (themes and sub-themes) during the scoping phase to help inform toolkit development.

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

2.4.3. Scoping phase summary

Building on the positive feedback to the prototype PE toolkit 'Shopping to Decarbonise' and with hands-on activities and visual examples of CRMs being the most consistent engagement preferences, we continued to develop the toolkit into something more concrete for the testing phase. The theme of 'shopping' was further explored, and evaluation methods were further refined.

2.5. Testing phase

The aim of this testing phase was to iterate 'Shopping to Decarbonise' into a test PE toolkit for the festival space and to assess the format of survey-based pre-post-activity evaluation. We exhibited this next iteration at the National Ploughing Championships or 'The Ploughing' in Co. Laois, Ireland (Fig. 1). The National Ploughing Championship is a major annual agricultural festival in Ireland, attracting approximately 250,000 people over the course of three days and posed as a prime opportunity to engage a large festival audience travelling to attend from across the country. At this festival, we tested the next iteration of the toolkit on 40 participants. Subsequently, as an additional assessment of this iteration, we carried out a student study that aimed to test the validity of the findings from the festival (Fig. 1). This was done at Ireland's largest university with a group of 9 third year business and marketing undergraduates over the course of three weeks.

2.5.1. The National Ploughing Championships, Co. Laois: methods and results

To further explore the supermarket theme as a relatable concept, this iteration of the PE toolkit was renamed as 'GreenDealz' with a supermarket style logo to match (Fig. 4) and the periodic table display was made to look like a supermarket shelf labelled as 'Aisle 2050' (Fig. 4). The CRM cubes were also given barcodes, so that practitioners could act as 'cashiers' and collect activity answers via mobile barcode scanning. Information about import reliance levels was more integrated into the experience as 'country of origin' style labels per CRM (i.e., '100% non-EU or 64% EU'). These visual additions were all part of ensuring the attraction of audience attention in the festival space (Bultitude and Sardo, 2012; Grand and Sardo, 2017). Time-sensitivity within the shopping activity was accounted for by reducing the number of CRM blocks to 10.

In an attempt to measure the level of interaction with GreenDealz material, the shopping activity mechanics were updated by creating a difficulty-based 'shopping score', whereby each technology (solar PV and wind turbines) had exactly 3 'correct' answers from the CRM cubes available (i.e., only 3 key functional CRMs were to be selected by participants) (Table 5). For each technology, there was one CRM with an "easy/leading" prompt (1 point), one with a "moderate" prompt (1.5 points) and finally one with a "hard" prompt (2 points) (Table 5). Thus participants would have to connect the CRMs with the technologies and each other, presumably using critical thinking to score higher (Bailin, 2002). Shopping scores were reported as a ratio (score achieved/maximum possible score). We also incorporated an interactive estimation task that asked participants to use blank cubes to illustrate the 2050 demand for certain CRMs per technology (e.g., 30 times more Gallium needed for 2050 EU

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

solar targets compared to current levels was represented by 30 blocks on a supermarket weighing scales). All steps of GreenDealz and correct answers were revealed to participants through visually stimulating animations on a computer screen.

Figure 4: (a) GreenDealz tabletop set-up (illustrations sourced and adapted from Freepik, 2025) (b) CRM cube example labels for Copper (image sources: Schwen, 2006 and Zander, 2007), Neodymium (image sources: Lavinsky, 2010; imagesofelements.com, 2016a) and Dysprosium (image sources: Lavinksy, 2010; periodic-table.com, 2025). For a full list of image sources for all CRM cubes see Fig. A1 (appendices). (c) field engagement with GreenDealz at The Ploughing exhibit (consent was given for photography but faces are covered for privacy).

To assess knowledge change, a pre and post evaluation was used. We used an objective knowledge assessment (i.e., assessment of what participants *objectively* know as opposed to "subjective knowledge" referring to what they *think* they know; Vicente-Molina et al., 2013). True or false questions and/or multiple-choice questions have successfully been used for assessing objective knowledge (Burton, 2005; Gronlund, 2006; Kuehl et al., 2023; Vicente-Molina et al., 2013; Zhou et al., 2017). Indeed, such tests are common in pre-post intervention evaluation across many different disciplines of education and PE and involve dichotomous scoring, where correct answers receive 1 point and incorrect answers receive 0 points (e.g., (Cottone and Byrd-Bredbenner, 2007; Huang et al., 2020; Leitão et al., 2022; Lemos et al., 2023). To ensure suitability for the festival space, we used true or false statements/questions because of their fast-paced answering style and designed three items that captured the main concepts of interest (Table 2). Due to the short time available to interact with participants in a festival-based setting, one item was included from the previously validated three item 'perceived need for CRMs' scale, scored as strongly disagree (1) to strongly agree (7) (Table 2) (Schuitema and Olomo, 2024). This short, on-the-spot survey (~3 minutes) was provided as

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

a 'quiz-like' online form (scannable by QR code) as an attempt to further integrate the evaluation into the festival interaction similar to embedded assessment measures (Schweingruber and Fenichel, 2010), while still retaining classical survey items.

Table 2: Survey items used during the testing phase. Grey boxes indicate the items used in the short version for the test PE toolkit at the National Ploughing Championships. White boxes indicate items that were used in addition to those in grey for the long version used during validation of the test PE toolkit with university students.

CONCEPT	ITEM
OBJECTIVE KNOWLEDGE (True (T) or False (F); 1 point = correct, 0 = incorrect).	A critical raw material is a raw material that is extremely rare and valuable but not important for society (F)
	The climate targets of the European Green Deal are reliant on critical raw materials to develop renewable energy (T)
	The EU carries out most of the mining and processing of critical raw materials that it needs (F)
	Critical raw materials are important for society and the economy but have high supply risk (T)
	Critical raw materials are used exclusively in European Green Deal agricultural projects (F)
	The EU relies on imports for most of its critical raw materials (T)
PERCEIVED NEED FOR CRMS (Likert scale, 1 = strongly disagree, 7 = strongly agree).	We need critical raw materials to produce more batteries for electric vehicles.
	We need critical raw materials to build more renewable energy sources like wind turbines and solar panels.
	I support the import of critical raw materials from countries outside Europe like China and Chile, if that helps make Europe Carbon Neutral by 2050.
SUBJECTIVE KNOWLEDGE (Likert scale; 1 = strongly disagree, 7 = strongly agree).	I do not understand why Europe needs critical raw materials for the European Green Deal.
	I do not comprehend what is meant when I hear the term 'critical raw materials'.
	I feel that I understand what a critical raw material is.
	I feel knowledgeable about how critical raw materials relate to the European Green Deal.
	I am familiar with the levels of European import reliance related to critical raw materials.
	I feel knowledgeable about the critical raw materials required to develop renewable energy technologies.
The Environmental Attitude Inventory: Brief version EAI-24 (Milfont and Duckitt, 2010).	

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

The National Ploughing Championships (N = 40) sample was spread between age groups, however most (35%) were 18-24 years. In the sample, 65% identified as male, 30% as female, and 5% as non-binary/transgender; 60% of the sample had a university or college qualification. Participants were nearly evenly spread between Leinster (45%) and Munster (40%), the remaining 15% came from outside these provinces.

Notably, we observed that despite their quick completion time (~3 mins), the pre-post online surveys detracted from participant experience at The National Ploughing Championships. Taking 3-minutes outside of GreenDealz to fill in an online survey felt incongruent with the surroundings and experience and removed communication between practitioner and participant.

The reliability of the objective knowledge three-item scale used at the festival ($\alpha < 0.10$) fell well below the acceptable threshold (Cronbach, 1951). This may be due to the use of dichotomous scoring for such a short scale and relatively small sample size. Consequently, results are unreliable, whereby prior objective knowledge appeared to be very high (median = 2 ± 1 with max possible score of 3) and no significant change between pre-post was present (Table 3). Participants ranked moderate to high in their prior perceived need for CRMs but did not show significant change from pre-post (Table 3). Thus, to understand how responses might have differed if time-restriction wasn't a key factor, we explored deeper evaluation during validation of the test PE toolkit with students.

2.5.2. Validation with student sample

During the validation with the student sample, pre and post surveys were completed one week before and after engaging with GreenDealz respectively. Both scales of objective knowledge and perceived need for CRMs were extended by including additional items that assessed the same key knowledge dimensions and by adding in the remaining two items from the perceived need for CRMs scale developed by Schuitema and Olomo (2024) (Table 2). With ample evaluation time, a subjective knowledge scale was included to test self-reported learning next to objective knowledge gain (Table 2). As CRMs and their link to renewable energy are tied to both the green transition but also the mining industry, we wanted to use this time to additionally explore any effect of pre-existing environmental attitude on shifts in knowledge or perceived need for CRMs. For this, we used the Environmental Attitude Inventory (EAI-24) (Milfont and Duckitt, 2010) during the pre-survey only. This standardised scale assesses general environmental attitude, which is also composed of two inversely correlated sub-dimensions "preservation" (i.e., preserving/protecting the environment) and "utilisation" (i.e., using the environment solely for anthropogenic gain). Hence, higher environmental attitude is related to higher preservation values, while lower environmental attitude is related to higher utilisation values. As with perceived need for CRMs, the subjective knowledge and environmental attitude scales were scored as strongly disagree (1) to strongly agree (7). Nine students completed this evaluation and engaged with GreenDealz. All were aged 18-24 years, 89% were female and 89% were EU citizens.

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

The reliability of objective knowledge was lower than is generally acceptable with $\alpha = 0.50$. However, this value is in-line with previous research employing dichotomously scored objective knowledge tests with even more than 6-items (e.g., Kuehl et al., 2023). Comparatively, subjective knowledge was found to be classically reliable with $\alpha = 0.72$. Prior objective knowledge was high (mean = 5 ± 1.12 with max possible score of 6), while prior subjective knowledge was moderate (mean = 4.06 ± 0.91 with max possible score of 7). Notably, subjective knowledge increased significantly to 5.87 ± 0.74 at post assessment as demonstrated via t-test, displaying a mean difference of 1.81 (95% CI 1.45 to 2.17), with $t(7) = 11.886$, $p < 0.001$, $d = 4.2$ (Table 3). However, objective knowledge did not change significantly from pre to post (Table 3). Hence, participants indicated that they felt significantly more knowledgeable after engagement with GreenDealz despite a lack of detected significant objective knowledge gain.

Table 3: Evaluation results across the testing and refinement phases for GreenDealz. Bold indicates where median ± median absolute deviation is given instead of mean ± standard deviation (due to non-normality). Asterisks indicate where pre to post results are significantly different. ϒIndicates scores that were compared and were not significantly different. Testing phase survey versions (i.e., short or long) are indicated next to each event.

Variable	**Testing phase**			
	The National Ploughing Championships (n = 40) – short version		Student validation (n = 9) – long version	
	Pre score	Post score	Pre score	Post score
Objective knowledge	**2 ± 0.64**	**3 ± 0.72**	5 ± 1.12	5.44 ± 0.73
Perceived need for CRMs	**4.5 ± 1.9**	**5 ± 2.0**	4.66 ± 1.10**	5.75 ± 0.56**
Subjective knowledge	n/a	n/a	4.06 ± 0.91**	5.87 ± 0.74**
General environmental attitude	n/a	n/a	5.17 ± 0.48	n/a
Preservation	n/a	n/a	5.32 ± 0.49	n/a
Utilisation	n/a	n/a	3.03 ± 0.56	n/a
Variable	**Refinement phase**			
	Control - 'Match-up' activity (n = 19)		Intervention – GreenDealz (n = 20)	
	Pre score	Post score	Pre score	Post score
Objective Knowledge-Embedded assessment	0.54 ± 0.17ϒ	0.54 ± 0.19	0.58 ± 0.23**ϒ	0.84 ± 0.13**

*p<0.05 **p<0.01

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

The reliability of the full three-item perceived need for CRMs instrument was previously found to be acceptable with $\alpha > 0.7$ (Schuitema and Olomo, 2024) and in this sample, $\alpha = 0.70$. Notably, despite the small sample size of the student population, a positive change in perceived need for CRMs (mean ± standard deviation) between prior (4.66 ± 1.09) and post (5.75 ± 0.55) values with a mean difference of 1.08 (95% CI 0.456 to 1.71) was confirmed to be significant via t-test ($t(7) = 4.08$, $p = 0.005$, $d = 1.44$; Table 4). As a comparative, when using the same individual item to measure perceived need for CRMs at The National Ploughing Championships (Table 2), there was no significant change recorded via Sign test (violation of normality) in the student sample.

A change score was calculated (post score-pre score) for subjective knowledge and perceived need for CRMs. According to a Pearson correlation analysis (Table 4), subjective knowledge change showed a moderate, positive relationship with general environmental attitude ($r = 0.34$) and its sub-dimension, preservation ($r = 0.38$). This indicates that those who are of higher environmental attitude (i.e., feel protective of their environment) tend to feel they learned more after engaging with GreenDealz. The strong positive correlation between environmental attitude and change in perceived need for CRMs ($r = 0.71$), also indicates that those with higher environmental attitude seem to experience an increase in their perceived need for CRMs. The sub-dimension of utilisation appears to most profoundly govern this relationship, as a strong negative and significant correlation exists between utilisation and change in perceived need for CRMs ($r = -0.79$, $p = 0.03$), while a more moderate positive correlation exists between the latter and preservation ($r = 0.53$) This implies that an openness to seeing the need for CRMs in decarbonising was more associated with stronger feelings of preservation of the environment since those showing strongest utilisation traits (i.e., anthropogenic dominance over the environment) were most associated with weaker changes in their perceived need for CRMs. Notably, there was a moderate negative correlation between subjective knowledge change and change in perceived need for CRMs ($r = -0.54$). This implies that pre-existing pro-environmental attitudes were more strongly associated with increased perceived need for CRMs than a feeling of increased knowledge about the topic.

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

Table 4: Pearson correlations between general environmental attitude, its dimensions of utilisation and preservation and measures of distinct change (subjective knowledge and perceived need for CRMs) recorded with students during the testing phase using the long version of the pre-post surveys.

Subjective knowledge change	1				
Perceived need for CRMs change	-0.54	1			
General environmental attitude	0.34	0.71	1		
Utilisation	-0.24	-0.79	-0.90	1	
Preservation	0.38	0.53	0.94	-0.69	1
	Subjective knowledge change	**Perceived need for CRMs change**	**General environmental attitude**	**Utilisation**	**Preservation**

2.5.3. Testing phase summary

It appears that engaging with GreenDealz elucidated an increase in the perceived need for CRMs and subjective knowledge among the student validation sample which is an encouraging find for our toolkit. Although, positive changes in these dimensions seem to be more associated with pre-existing pro-environmental attitudes than with each other. The same change results were not seen at The National Ploughing Championships, likely due to the comparatively limited number of perceived need for CRM items used and of course the lack of a subjective knowledge test. However, by extrapolation, the same changes could be expected in the festival space if the full survey was employed, especially considering naturally larger sample sizes, although sample characteristics may also account for differences. Additionally, objective knowledge did not significantly change in either testing phase sample (Table 3), despite the inclusion of an additional three objective knowledge survey items during student validation (Table 2). This indicates that for detecting objective knowledge gains using a dichotomously scored scale in the festival environment, more than six items would need to be included, as is more commonly employed in surveys (Cottone and Byrd-Bredbenner, 2007; Kuehl et al., 2023; Leitão et al., 2022; Vicente-Molina et al., 2013; Zhou et al., 2017). However, based on observations at The National Ploughing Championships and due to festival-based time constraints and concern for the engagement flow, this level of survey expansion was not possible, nor practical.

Therefore, it was deemed beneficial to further integrate the pre-post evaluation into the experience of GreenDealz to more fully achieve an “embedded assessment” strategy. Thus, as we are most interested in the objective knowledge dimension, to learn about actual knowledge gains in participants, we deduced that a festival-friendly, embedded objective knowledge assessment may require scoring systems with continuous data if subtle levels of pre and post change are to be detected,

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

especially where only three items are used in the interest of timesaving. As such, updates for the final PE toolkit again centred around evaluation and were done through the refinement phase (Fig. 1).

2.6. Refinement phase

The aim of this phase was to refine the evaluation methodology into a more GreenDealz embedded pre and post assessment strategy. We carried out this phase across three Irish science and arts festivals/events during Science Week in Ireland: (i) Science at Marina Market, Co. Cork; (ii) Louth Science Fair, Co. Louth; (iii) "Foram", a geoscience art exhibition in Co. Dublin. The two former events drew crowds in their hundreds, while "Foram" attracted an audience of approximately 40 people.

2.6.1. Science Week: methods

The concept of embedded assessment (EA) offered a unique solution to achieve better integration of evaluation into the GreenDealz experience (Schweingruber and Fenichel, 2010). To formulate the toolkit EA, a set of three tasks were created that ultimately used the same GreenDealz props, i.e., weighing scales, cubes, shopping baskets, on-screen visuals and information, drawing on inspiration from the estimation task employed during the testing phase. These tasks were shown on screen and read aloud by the practitioner, whereby participants had to complete the tasks using the props in front of them. The tasks reflected understanding of the core principles previously covered in objective knowledge assessment. Hence, this EA was a more interactive and task-based method of assessing objective knowledge either side of participating in GreenDealz. The GreenDealz shopping activity tasks were unchanged. The three EA tasks, with (a) their props (b) correct answers and (c) rationale were as follows:

1) Place any item(s) that contains a critical raw material in the shopping basket.
    a. *Props: Participant(s) are provided with a shopping basket and 7 cubes that each represent a random item/object (Fig. B4, Appendix A1).*
    b. *Correct answer: All 7 items (i.e., 7 cubes).*
    c. *Rationale: This task relates to understanding the definition of a CRM, i.e., a material that is important for society and thus is present not just in green and digital technologies but also everyday items.*

2) Compared to a gas-fired power plant, how many times less OR more mineral resources are needed (on average) for an onshore wind farm? Place cubes in the shopping basket to illustrate (1 cube = 1 times, 2 cubes = 2 times and so on).
    a. *Props: Participant(s) are provided with a shopping basket and 9 cubes. Therefore, they are told they can choose up to 9 cubes. They are then asked to say whether they believe the answer is less (-) that number of*

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

cubes or more (+). This negative to positive scale allows greater levels of change between pre and post scores to be detected.

b. *Correct answer: 9 times more (i.e., +9 cubes)*

c. *Rationale: This task relates to the demand for CRMs in developing renewable energy.*

3) Of the 49 EU critical (and strategic) raw materials, how many have an import reliance greater than 75%? Choose a number of CRMs between 0 and 49.

   a. *Props: Participant(s) are directed to the 49 green coloured CRM cubes indicated on the periodic table or 'Aisle 2050' and asked to choose a number between 0 and 49.*

   b. *Correct answer: 37 (however, as this import reliance % can change year on year, the highest possible score of 49 is what indicates the best knowledge/awareness of supply risk).*

   c. *Rationale: This task relates to the concept of supply risk and how most CRMs are highly sourced from imports therefore making them susceptible to supply chain disruptions.*

Total participant scores were calculated as a ratio: the sum of scores/max possible score (where max possible score = 7 + 9 + 49 = 65). Hereafter, this assessment is referred to as objective knowledge-EA.

To ensure robustness of this assessment, this phase incorporated a quasi-experimental design, which is appropriate for field-based settings, by inclusion of a 'control' activity to test against GreenDealz, i.e., the 'intervention' (Abrahamse, 2016). This control activity was a 'match-up' task that required participants to examine rock and ore samples and match them to corresponding images on a geological map of Ireland, wherein they would learn about the origin of some CRMs and their uses. Thus, the same objective knowledge-EA was used as control activity pre-post assessment. Control and intervention groups were divided across festivals/events, where total participant counts in each group were monitored to ensure equal or close sample size.

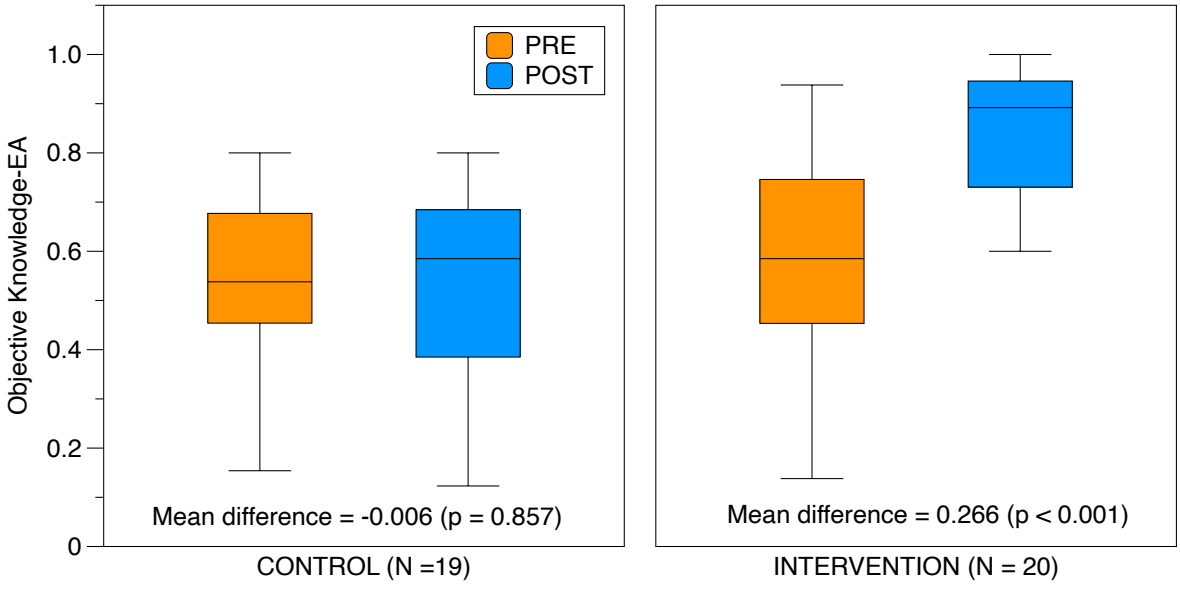
2.6.2. Science Week: results

The control group (N = 19) were predominantly (68%) aged 35-44 years with 58% residing in Munster, while the intervention group (N = 20) were slightly more diverse in age, although mostly (55%) spread between 35-54 years and 65% residing in Leinster. Gender was split close to 50/50 between female and male across both groups. Nearly all participants were of university/college qualification (control 89%, intervention 85%).

Results from a paired t-test show that the mean difference of 0.266 (95% CI 0.159 to 0.373) between pre-post objective knowledge-EA scores for the intervention group was significant ($t(19) = 5.204$, $p < 0.001$, $d = 1.16$), whereas, the mean difference of -0.006 (95% CI -0.080 to 0.067) between pre-post objective knowledge-EA scores for the control group was not

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

445 significant (t(18) = -0.183, p = 0.086, d = -0.042) (Fig. 5). Additionally, pre scores between the control (0.54 ± 0.17) and intervention (0.58 ± 0.23) groups were not significantly different (t(37) = -0.541, p = 0.591, d = -0.17) indicating that participants in the control and intervention group had the same baseline knowledge level, which was relatively moderate. Lastly, observations indicated that with the EA tasks communication was maintained, the interaction felt more streamlined than assessment in prior phases, and EA appeared to evoke a sense of playfulness in participants. Thus, according to the pre-
450 post scores achieved between the control and intervention samples combined with observations, this method of objective knowledge assessment appears more successful in capturing change than testing phase evaluation while maintaining interactivity.



455 **Figure 5: Distributions of objective knowledge-EA scores between pre-post within the control and intervention groups, along with results of paired t-tests.**

2.7. GreenDealz interaction measured across the testing and refinement phases

Interaction with GreenDealz could be measured by assessing what CRM cubes participants chose for each technology based
460 on the prompts i.e., their 'shopping score'. As GreenDealz shopping tasks remained unchanged between the testing and refinement phases, we pooled this data for analysis except when comparing to specific phase evaluation data. For both technologies, most participants correctly chose the CRMs that had the easiest prompts (91% chose Silicon for solar PV and 74% chose Neodymium for wind turbines; Table 5). The next most popular CRM choice for both technologies was Copper (65% chosen for solar PV and 62% chosen for wind turbines, Table 5), which again indicates a draw towards moderate to easy

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

prompts (Table 5). However, for each technology, only 22% of participants correctly chose the CRMs with the most difficult prompts (Gallium for solar PV and Dysprosium for wind energy; Table 5). Instead, participants mostly chose Lithium as their third CRM for solar PV (59%) and Titanium as their third CRM for wind turbines (49%). As a result, the average 'shopping score' across all events for the testing and refinement phases was 0.49 (i.e., on average participants were 49% correct) (Fig. 6, Table 5). Therefore, on average, it can be said that participants showed moderate interaction with the information on the CRM cubes while loading their shopping baskets at GreenDealz, with a greater likelihood to rely on easy clues than to also apply greater analysis (i.e., connecting CRM prompts) in completion of the task.

Table 5: GreenDealz shopping scoring system, prompts and compiled results from the testing and refinement phases. Prompts are designed to be easy, moderate and hard. High scores can be achieved with greater analysis by matching relevant CRM prompts together. All other CRM blocks chosen (not shown in table) were scored as zero.

Solar PV shopping basket			
Correct CRMs:	Silicon (Si) – 1 point	Copper (Cu) – 1.5 points	Gallium (Ga) – 2 points
Prompts:	1. Partially conducts electricity 2. Helps turn light to electricity	1. Electrical wiring 2. Weather resistant	1. Partially conducts electricity 2. LED lights
% chosen by participants:	91%	65%	22%
Wind turbine shopping basket			
Correct CRMs:	Neodymium (Nd) – 1 point	Copper (Cu) – 1.5 points	Dysprosium (Dy) – 2 points
Prompts:	1. Super magnets 2. Spinning magnets = electricity	1. Electrical wiring 2. Weather resistant	1. Maintains magnetic abilities 2. Infrared technology
% chosen by participants:	74%	62%	22%

To delineate any potential relationships to the shopping scores achieved in GreenDealz across the testing and refinement phases, we conducted correlation analyses with any relevant variables of change (knowledge and perceived need for CRMs) and pre-existing environmental attitudes (Table 6). The testing phase validation results with students (reported in Sect. 2.5.2.) suggests there was a moderate, positive relationship between shopping score and more positive pre-existing environmental attitude i.e., 'preservation' ($r = 0.56$). Hence, this could mean that those with higher environmental preservation attitudes are willing to interact more strongly with GreenDealz. There was also a weak to moderate positive relationship between change

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

in perceived need for CRMs and shopping score within this student sample (r = 0.37), which further suggests that there was a significantly increased perceived need for CRMs after interaction with GreenDealz. Furthermore, there is a weak, negative relationship between change in objective knowledge-EA during the refinement phase and shopping score (τ_b = -0.22; via non-parametric Kendall's Tau-b correlation). This suggests that absolute knowledge enhancement was not dependent on whether participants answered correctly during 'shopping', hence simply participating in the activity was enough to gain objective knowledge.

Table 6: Correlations between GreenDealz shopping score and variables with distinct change across the testing and refinement phases (subjective knowledge and perceived need for CRMs change with students and objective knowledge-EA change during science week). Environmental attitude dimensions measured with students are also included. All testing phase correlations are represented by Pearson coefficients while Kendall's Tau-b correlation$^{\tau_b}$ was used during the refinement phase due to non-linearity of shopping score and objective knowledge-EA.

	Shopping Score	*Phase*
Objective knowledge-EA change	-0.22$^{\tau_b}$	*Refinement (Science Week)*
General environmental attitude	0.40	*Testing (student validation)*
Preservation	0.56	
Utilisation	-0.03	
Subjective knowledge change	-0.13	
Perceived need for CRMs change	0.37	

During GreenDealz 'shopping', people appeared to enjoy the tactile nature of the cubes and often seemed most enthusiastic about getting their answers correct when working in groups rather than alone. It was also observed that optimum group size was about three, whereby any more than four people often became difficult to manage. Therefore, shopping scores across the testing and refinement phases were compared via Mann Whitney U-test (Shapiro Wilk $p < 0.001$) between those that took part in GreenDealz as single participants and those that worked in groups. Group participants (mean rank = 48.83) had a significantly ($U = 213.5$, $Z = -3.696$, $p < 0.001$) higher shopping score than single participants (mean rank = 29.36; Fig. 6). Hence, interaction with the GreenDealz CRM cubes appears to be higher when working together, perhaps indicating stronger discussion during decision making. This suggests that the average shopping score of 0.49 may be skewed by the higher proportion of single participants (49 out of 69 total participants across the two phases), thus we may expect a higher average shopping score if more participants were in groups.

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

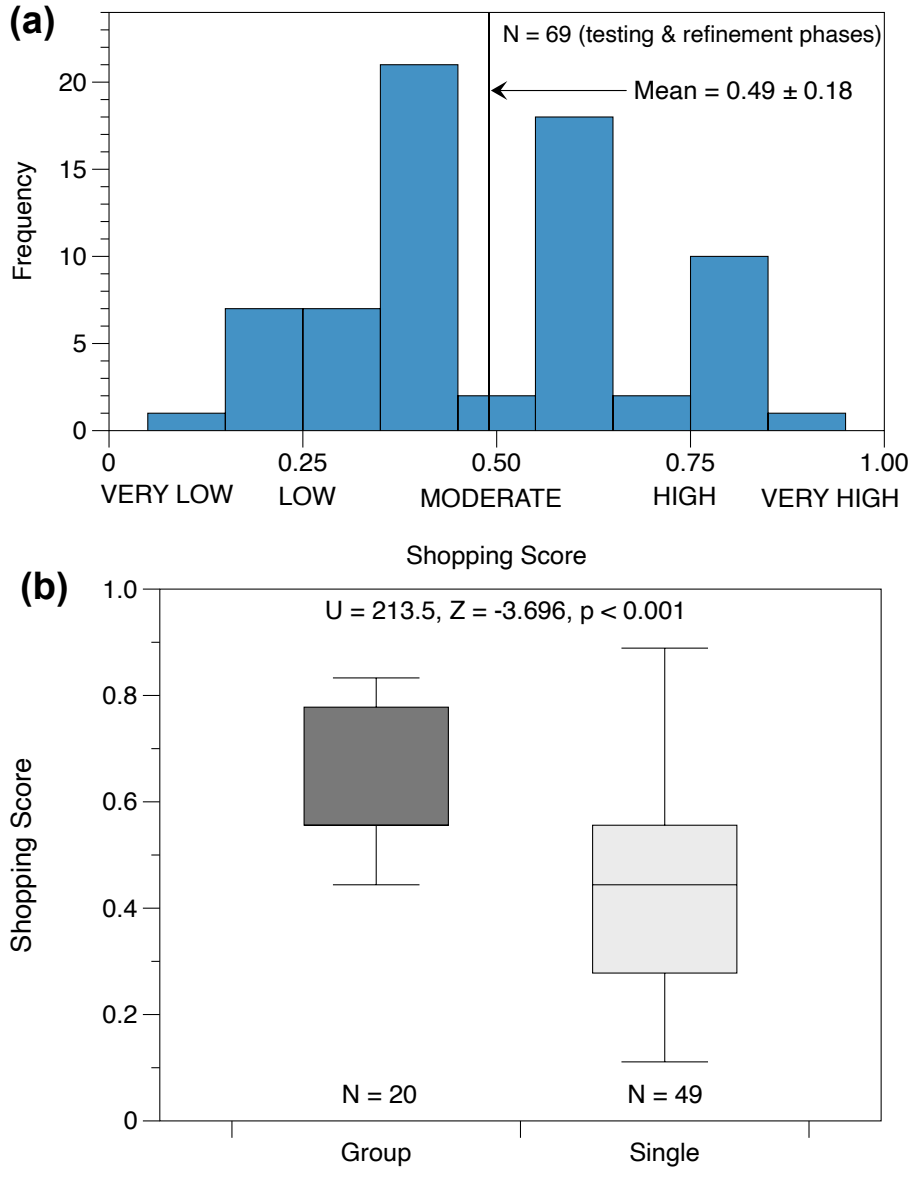


Figure 6: (a) Shopping score distribution across the testing and refinement phases. (b) Distribution of shopping score between groups and single participants and results of a Mann Whitney U test.

510

When comparing GreenDealz shopping scores between the different festival environments across these phases, it appears that The National Ploughing Championship's agriculturally-interested audience (N = 40, mean = 0.52 ± 0.17) showed significantly higher shopping scores compared to the audience across Science Week events (N = 18, two outliers removed to fulfil t-test assumptions, mean = 0.38 ± 0.14) with a mean difference of 0.142 (95% CI 0.05 to 0.234; t(56) = 3.108, p = 0.003, d = 0.882).

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

However, there was also relatively more group participants among the respondents from The National Ploughing Championship (~30%) compared to the Science Week sample (~10%) which may have played a part in this difference. There was no indication that shopping score differed significantly by any demographic measure across the testing and refinement phases.

3. Discussion

3.1. Toolkit effectiveness

From the scoping to the refinement phase, development of the PE toolkit GreenDealz has been driven by audience feedback, responses and field observations. Reflectively, the overall aim was to create a PE experience that enhances audience engagement with the role of CRMs in achieving the EU Green Deal and evaluates changes in knowledge in a festival appropriate manner. Thus, we aimed to create an engagement activity that lasted no longer than 15 minutes, including the evaluation, as in previous developmental research for PE activities, (e.g., Vergunst et al., 2024). In terms of knowledge enhancement, it is worth noting that the generally high education levels captured across this entire study are reflective of the Irish population, especially for those between the ages of 25-45 years (Level of Education Census of Population 2022 Profile 8 - The Irish Language and Education - Central Statistics Office, 2024).

The results demonstrate that GreenDealz has real potential to successfully enhance audience knowledge on the topic of CRMs and their link to the EU Green Deal (Table 3, Fig. 5). It was clear that the interactive nature of the toolkit was essential to attract and engage participants until the end, which is in line with earlier research on what informal audiences value most in science communication (Bultitude and Sardo, 2012; Jensen and Buckley, 2014; Roche et al., 2016b; Sardo and Grand, 2016). This was less so when surveys were used in their traditional and rigorous form, especially for the festival environment. As such, this study builds on previous research that highlights embedded assessment as a more suitable and effective option for evaluation in the informal educational space (Becker-Klein et al., 2016; Schweingruber and Fenichel, 2010).

Prior research also suggests that when it comes to issues related to the green economy, public opinion is likely biased by the first piece of information received (Poluektova et al., 2024). Notably, through the many interactions with GreenDealz, it was clear that it acted as a springboard for wider conversations on the topic, with many participants remaining in conversation with the practitioner after completion to discuss CRMs and green energy further. This is a promising observation when one of the great goals of science communication is to stimulate public dialogue and introduce new ways to facilitate conversation between scientists and public audiences (Illingworth, 2020, 2023).

The results also imply that GreenDealz garners significantly higher interaction (e.g., potentially higher levels of critical thinking or informed decision making; Bailin, 2002) when working in groups. This is a promising result, especially for informal

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

educational settings like festivals where people often attend in groups and are more inclined to engage in activities together. Moreover, it could mean that the discussions that start during the activity may continue in social groups and thus spread to wider social networks. Similarly, the greater tendency then of single participants to rely on easier and more leading clues when choosing CRMs for each shopping basket is testament to the quick and easy interaction desired by festival participants (Grand and Sardo, 2017) perhaps especially when engaging individually in such fast-paced environments.

Furthermore, it is valuable that correlation analysis findings show that GreenDealz shopping scores do not appear to significantly affect how much participants learn (Table 6) as this reinforces the notion that simply encountering and engaging with GreenDealz is the more important channel to coming away with enhanced knowledge rather than being 100% correct.

It is noteworthy that people's third most popular choices for solar PV and wind turbine CRMs were Lithium and Titanium respectively, because Lithium is an increasingly well-known CRM by the public, as society advances into the technological and battery age (Agusdinata and Liu, 2023; We rely heavily on lithium batteries – but there's a growing array of alternatives, 2025) and Titanium is also prevalent in popular culture for being a metal of great strength and durability (e.g., The Marvel Universe; American Chemical Society, 2013; Robinson, 2012). Perhaps these properties and publicity had some impact on participant choices for these technologies, in which case would be somewhat indicative of the importance of relatability as scoping phase evaluation suggests, but also how relevance and meaning are key in geoscience communication (Ford, 2019). Lastly, in the realm of interaction, it is also interesting that The National Ploughing Championship audience (although there are more groups) shows higher shopping scores than those from the Science Week festivals. This is encouraging because it shows that even such a geoscientific/technical based PE experience is appealing to audiences that are less likely to know they will encounter science at a festival event, whereby it is often the aim of practitioners to be able to reach the potentially uninterested or 'residual' public (Miller, 1983).

Finally, despite the small sample size, indications that engagement with GreenDealz may have elicited an increase in perceived need for CRMs among the student sample are interesting, especially in the sense that those who showed higher environmental preservation attitudes were significantly related to a greater increase in perceived need for CRMs (Table 4). This is perhaps an unexpected finding considering that CRMs are inextricably linked with the mining industry, which is often associated with poor environmental standards and ethics in the public conscious (Agusdinata and Liu, 2023; Niranjan, 2023; Petitjean and Verheecke, 2023; Rogers et al., 2024). However, this information was gathered from a group of students aged 18-24, which could hint at a shift in value association within younger generations, i.e., a greater understanding that to decarbonise and thus adapt to climate change may involve an increased role from raw material extraction. Although, this is said extremely tentatively, as this study was small and not representative enough of a wider population.

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

3.2. Broader implications

GreenDealz represents a novel toolkit offering a unique activity that engages the public with the role of CRMs in achieving the EU's Green Deal targets, combined with an embedded assessment that is integrated via an interactive experience. The iterative method used to develop this toolkit has shown its potential in creating a data driven, educationally effective and evaluative informal PE activity. GreenDealz in its current form has been developed and adapted to suit the festival environment while attempting to remain educational in a budget friendly manner, therefore it can be used as a tool for most practitioners who wish to engage with publics on this topic, they need only use the material information and guidelines (appendices).

The strength and added value of GreenDealz lies in enhancing knowledge about the topic of CRMs and their link to the EU Green Deal. This study suggests that GreenDealz is suitable for future use at informal educational settings. Notably, GreenDealz may act as a template on which to build, budget dependent, whereby the activity itself could be upscaled into a 'real-life' shopping experience at a larger festival exhibit, where stronger gamification could come into play and players could race to fill their renewable energy baskets, learning about CRM stock shortages in the process. Alternatively, GreenDealz could be digitised and brought into the online space, whereby players may again 'shop' for CRMs within a virtual world, learning the same key concepts. Furthermore, this toolkit as it stands is highly practitioner dependent and necessitates that practitioners are well versed on the content of the engagement whereby consistent participant direction is also required. Therefore, the development of an online/digital version of this toolkit can seek to make GreenDealz a more stand-alone and standardised activity in which a participant can approach and understand the tasks in their own time; Thus, the development of this toolkit potentially represents a first step in expanding a PE idea for educating and engaging with audiences on this topic.

Overall, this research suggests that people have a keen interest in engaging in activities about CRMs and their relevance to the green transition and have important insight to offer geoscientists, social scientists and educators. Since the festival environment offers little space and time to carry out in-depth evaluation, future work should incorporate a more rich and qualitative approach to understanding the participant experience of GreenDealz. Such a study should evaluate pre-existing knowledge and perceptions and whether the toolkit has the power to meaningfully effect this.

Conclusion

The need for a sustainable and secure supply of CRMs to decarbonise the EU economy is an ever pressing and surmounting challenge facing European society. It is imperative that publics are engaged on this matter and that evaluation of public opinion and awareness on the issue is ramped up. The informal educational space provides ample opportunity to rise to this public engagement challenge and as such we have developed a toolkit that is built on this need. Our goal was to create a novel experience that enhances audience knowledge about CRMs and the EU Green Deal within informal settings like festivals. We have achieved this through data driven and in-field public engagement research and analysis. This research highlights the

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

usefulness of iterative toolkit building and the need to develop and test a public engagement toolkit live. This study also supports the need for fast-paced and interactive forms of evaluation without interruption of participant experience, with an acceptance of the loss of more rigorous survey techniques in favour of human experience. GreenDealz provides a template on which to build, whereby future iterations of this simple concept could take many forms, all with the goal of better engaging publics with the important and timely subject of CRM importance in the green transition.

Appendices

The full GreenDealz toolkit with materials, set-up and instructions can also be found online at: https://www.icrag-centre.org/greendealz/

Appendix A: GreenDealz Kit and Materials

Embedded assessment materials

- 16 wooden cubes (3 cm^3), 9 painted green and 7 used for CRM item labels (Figs. A3 and A4).
- CRM item label/sticker template - change to any of choice but for scoring, all items must contain CRMs (Fig. A1).
- Mini shopping baskets (Fig. A4).

GreenDealz shopping materials

- 10 wooden cubes (3 cm^3), all painted green and covered by CRM stickers (Fig. 4 and A1).
- CRM sticker template – change to any of your choice but must be arranged so that only three available CRMs (per technology) are key functional components (Fig. A1).
- Mini shopping trolleys (Fig. 4).
- GreenDealz ‘supermarket aisle 2050’ as an A2 laminated sheet (Fig. A2) – update import reliance labels as necessary.

General materials and items

- Data recording sheet OR a number/barcode scanning mobile app.
- Participant ID tokens or any label types for anonymous ID’s.
- Monitor or laptop and presentation showing visuals, information and results.
- Sticker paper and cutting tools (sticker maker or scissors).

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

Figure A1: The 10 GreenDealz CRM shopping cube labels (includes CRM names, images of pure CRMs, their primary ores/extractive material, shopping clues/prompts and barcodes. CRM cubes include Lithium (pure image source: Encyclopaedia Britannica 2025; ore image source: Lundberg, 2017) Titanium (pure image source: imagesofelements.com, 2016b; ore image source: Sepp, 2013), Rhodium (pure image source: imagesofelements.com, 2016c; ore image source: Schwen, 2006), Bismuth (pure image source: imagesofelements.com, 2016d; ore image source: Geology.com, 2025a), Erbium (pure image source: imagesofelements.com, 2016e; ore image source: Lavinsky, 2010), Gallium (pure image source: imagesofelements.com, 2016f; ore image source: Geology.com, 2025b), Copper (pure image source: Zander, 2007; ore image source: Schwen, 2006), Neodymium (pure image source: imagesofelements.com, 2016a; ore image source: Lavinksy, 2010), Dysprosium (pure image source: periodic-table.com, 2025; ore image source: Lavinksy, 2010) and Silicon (pure image source: chemistrylearner.com, 2025; ore image source: Wilkins, 2015).

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

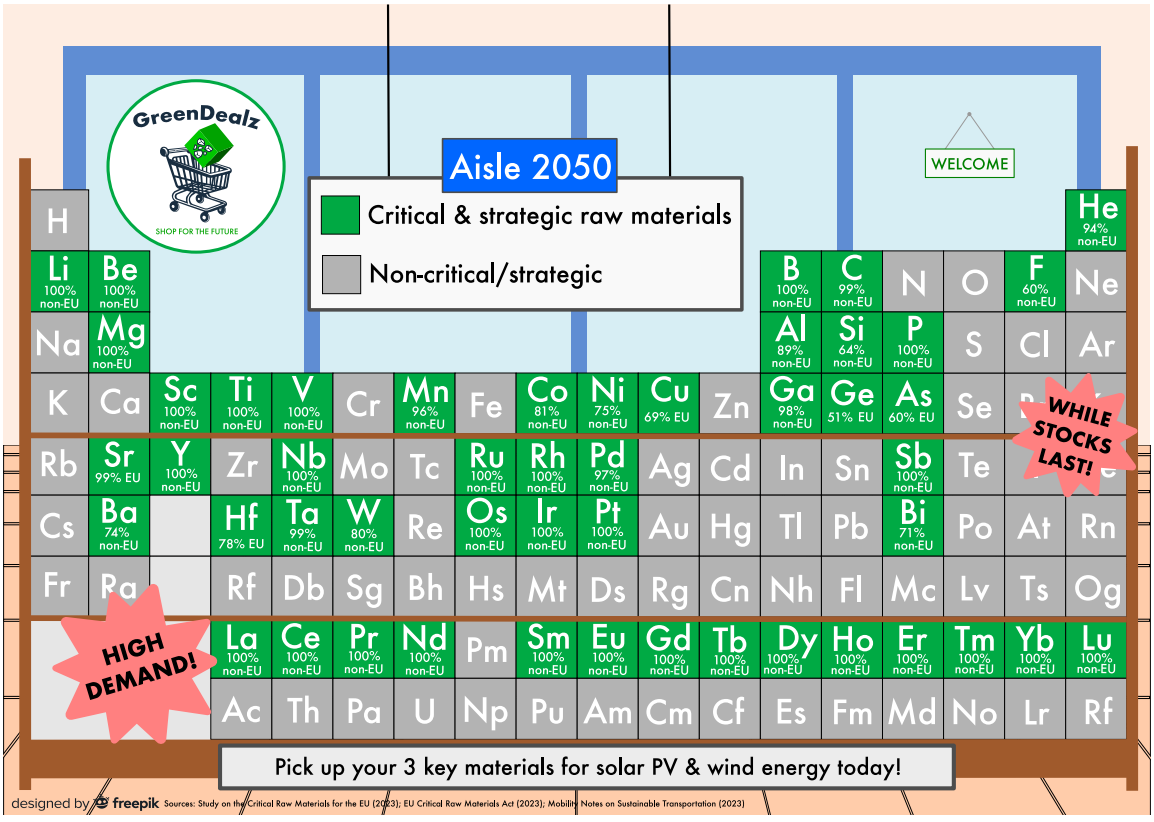


Figure A2: GreenDealz 'supermarket aisle 2050' (to be used in A2 format with 3cm^3 cubes). Supermarket aisle background (except for logo) is adapted from Freepik, 2025.

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

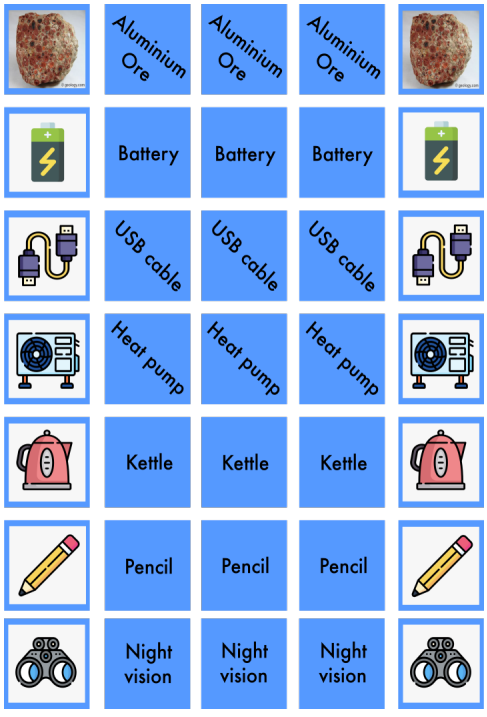


Figure A3: Item cube labels for task 1 of the embedded assessment. Cubes include Aluminium ore (image source: Geology.com, 2025b), a battery, USB cable, heat pump, kettle, pencil and night vision goggles (images sourced from Freepik, 2025).

Figure A4: Embedded assessment props; 9 plain cubes, CRM item cubes (image sources: Freepik, 2025; Geology.com, 2025b) and shopping baskets.

https://doi.org/10.5194/egusphere-2025-3753
Preprint. Discussion started: 2 September 2025

Appendix B: GreenDealz user guidance

Key learnings (and engagement moments)

1. CRMs come from the Earth and are important for renewable energy systems & society (assessing cubes for properties and pictures).
2. CRMs can have supply risk due to import reliance and/or demand (i.e., both wind and solar need a Copper cube, import reliance labels on cube places within Aisle 2050).
3. The EU Green Deal cannot be achieved without CRMs (provide information and visuals on screen throughout engagement).

Code/data availability

The data collected from participants for this study is not available for sharing as per ethical considerations.

Author contribution

LB and FM developed and designed the iterative phases of toolkit development. LB created the toolkit and conducted all analyses and data processing. GS was consulted for data collection and assessment techniques. LB was first author of the manuscript text. GS and FM gave constructive and on-going editorial feedback and critique.

Competing interests

There are no competing interests to declare.

Ethical statement

This research study received ethical approval from the University College Dublin Office of Research Ethics (LS-LR-24-188-McAuliffe). All participant data was kept anonymous. All data is securely held within University College Dublin. Analysis and interpretation reflect the authors' conclusions and hypothesis based on the data.

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