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SolVis: A pilot study to facilitate understanding of real-time solar energy production through energy visualizations in learning environments

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Abstract. The transition to a carbon neutral society requires actions on all levels of society. Hereby, renewable energy - especially considering the current European energy crisis – such as solar energy will play an increasing role. To promote a more extensive use of solar energy and thus contributing to a faster energy transition, it is valuable to engage all citizens, not least children. How can real-time visualization of solar energy production in learning environments contribute to increased understanding of energy production and consumption? Educational environments can be a powerful platform to cultivate an interest in more environmentally and sustainable behaviour at an early age. However, energy is intangible, abstract, and difficult to grasp for non-experts. Digital tools incorporating energy visualization may be able to facilitate an increased understanding of energy units and measurements. The City of Gothenburg, Sweden, has the ambition to place photovoltaics on all roofs of schools and kindergartens, a process that is already in progress. The solar energy production is measured in real-time and only used for building operation management. This paper presents a study that develops a concept for a digital and educational visualization tool for school children aged 9 to 12, with the goal to engage, facilitate a lasting learning outcome, and awaken curiosity in solar energy. A prototype of a real-time visualization tool was developed, which in a playful way visualises the solar electricity production of the school property and compares it to the energy consumption of everyday activities, displayed on a centrally placed screen in the school. It was installed in four pilot schools and evaluated with 233 pupils. Results indicate several potentials of the visualization: to communicate local solar energy production to pupils, triggering thoughts, ideas, and a will to continue to learn more about solar energy production.

1. Introduction
The transition to a carbon neutral society requires actions on all levels of society. Hereby, renewable energy, such as solar energy will play an increasingly important role; especially considering the current European energy crisis. Sweden has set the ambitious goal for a transition to 100% renewable electricity by year 2040 [1]. As of today, there is no specific goal regarding solar energy, but given the scalability and versatile nature of solar energy production, it will continue to be an important energy source.

Solar energy production is well suited for integration in the existing urban built environment, and municipalities are one of the key actors in a large-scale transition towards the use of renewable energy nation-wide. The City of Gothenburg, Sweden, is one of 100 cities selected by the European Union with the goal to be climate-neutral by 2030 [2]. The city has the ambition to place photovoltaics (PV) on the roofs of all municipal buildings, especially schools and kindergartens; a process that is already in progress. By default, solar energy production is measured in real-time and monitored for building operations and management; this opens for exploring the potential of translating the data into more comprehensible information and, through design and digital energy visualizations, communicating the environmental gains of solar energy to a wider audience.

An increase of small-scale implementations of solar energy production, both in private households as well as public buildings, increases individual citizens' potential in contributing to the building of reliable, resilient, and renewable energy systems nation-wide. Focusing on learning environments for the expansion of small-scale solar production is making effective use of existing built structures while also providing the opportunity to build energy awareness and environmental stewardship in present and future citizens already at an early age. [3,4] Increased knowledge and understanding of energy systems through environmental education, is a crucial step in the process of enabling children, i.e., the future citizen adults, to build more sustainable and resource responsible communities and societies [5,6]. Indirectly learning from local energy systems, such as solar panels on the own property, is of high pedagogical value, as it can be easier to absorb local, place-based knowledge production that fosters place-attachment and highlights relations between actions and outcomes [3,7].

This paper discusses the development of concepts for digital visualizations of solar energy in educational environments, exploring the following research question: How can real-time visualizations of solar energy production in learning environments contribute to increased understanding of energy production and consumption? The study is based on the project *SolVis - concept for visualizing solar energy,* which develops a concept for a digital educational visualization tool placed in school environments, targeting pupils aged 9 to 12. The goal of the visualization is to engage users, facilitate a lasting learning outcome, awake curiosity for the installed solar panels specifically, and for renewable and independent energy systems generally. By educating children about solar energy and its contribution to a sustainable energy system, the SolVis project aims to raise awareness and cultivate an interest in more environmentally conscious and sustainable behaviour in the future. This transdisciplinary project joins competences from energy research, urban design and planning, pedagogy, visualization, and interaction design.

2. Background
As they are the future adult citizens, it is essential to actively engage children in the transition towards and the development of more sustainable and equitable future societies [3,4]. There is a need to establish and promote *ecological literacy* [8], or *eco-literacy* [9,10] i.e., the understanding of natural ecosystems and the conditions and principles of creating sustainable human communities and societies within and in balance with such systems. This paper pays special attention to the promotion and development of *energy literacy* [11], i.e., the understanding of what energy is, how it is produced, stored, measured, and used; key knowledge in reducing the environmental impact of energy consumption [4]. Energy is intangible, abstract, and difficult to grasp for non-experts, which calls for methods and tools for simplified communication of energy systems to children [12]. Educational environments can be

powerful platforms for fostering of ecological literacy, environmental concern, curiosity, and agency through place-based educational approaches [3,7,13].

2.1. Energy education

A recently published report [14] shows that children experience anxiety associated with the future and the climate; a feeling of powerlessness to influence, and disappointment in adults who do not take their responsibility in meeting the goals of international climate agreements. The report [14] emphasizes that it is not enough to help children to emotionally deal with their worries; there is a need for actual measures that reduce environmental threats, as well as actions to educate children to meet the future challenges of climate change and scarce resources [5,6]. Young children have potential to be both actors and agents of social and environmental change [15]; prior to adolescence (approximately age 9-12) children start to develop environmental values and curiosity about the world, and are more likely than teenagers or adults to aquire positive attitudes towards nature and the environment [16].

The concept of *ecological literacy* is a term which has been subject to many different interpretations and applications [8]; it is used to descibe the knowledge and understanding of natural systems necessary for informed decision-making. While *eco-literacy* stems from the ecological field, it is a concept also extending into the broader humanities [8] focusing on the principles and conditions of building sustainable human societies within and with the natural environments, through environmental education and a reconstruction of educational systems [9,10]. Reducing our current societies' dependency on fossil energy, thus limiting the environmental impact of energy production and consumption, is a key environmental and educational issue, calling for the energy education of future citizens [4].

This study specifically seeks to promote *energy literacy* [11], which includes knowledge and understanding of energy systems, production, and consumption, as well as the ability to make informed decisions based on that knowledge [17]. The current understanding of energy systems limits both individual and systemic behaviour change; establishing energy literacy has the potential to influence energy consumption behaviours of children and adults [18,19]. Furthermore, it is not enough to learn about energy through theoretical knowledge transfer of statistics and numbers; there is a need for experimental, place-based educational approaches, triggering curiosity and awareness, and strengthening the engagement and participation of children [3,4]. Following the belief that knowledge and understanding is better established through the facilitation of self-learning – as opposed to a traditional education process supporting the transferring of facts from teacher to learner [20] - pupils should be actively engaged in their own learning and encouraged to integrate with knowledge on their own terms. Rather than students being viewed as a passive recipient of knowledge, such an approach supports a "bottom-up counter-flow" [20: 742] of demand for information. Engaging children in energy education with a strong connection to their surroundings, especially in informal learning environments supporting *self-instructural* learning, can raise questions, trigger curiosity, and stimulate active thinking [20,21].

2.2. Design and (eco) visualization

Place (built and natural environments) and design (images, space, and form) has great potential to facilitate an increased understanding of energy systems and environmental awareness, through active engagement and participation of the intended audience [20-22]. Digital design and visualization tools that aims at facilitating and promoting *ecological literacy* can be framed under the umbrella concept of *eco-visualizations;* they can be for instance "data-driven animations that display ecological information of any sort in real time" [23:154]. Combining knowledge from the fields of responsive architecture, media art, information visualization and sustainable design [23], eco-visualizations can work together with the built environment to communicate local and natural phenomena, emphasizing the connection between humans, buildings, and the ground [3].

So far, the use of eco-visualizations has mainly been directed at promoting behaviour change related to energy usage patterns and has mostly been tested out in homes and workspaces, close to the end user. [24]. Energy visualization initiatives focusing on younger age groups or in public places – such as libraries, community centers or school environments – is so far relatively unexplored, as well as initiatives combining data of energy production and consumption are very few [24]. In a short-term perspective, renewable energy systems are more in flux than fossil energy; human societies will need to learn to allow energy supply variations to influence our behaviour, thus indicating the need for new ways to communicate energy consumption and production patterns to users in real-time. Comparing small-scale and local statistics of energy production with one's individual energy consumption also has the potential to further deepen the understanding of energy units and measurements, compared to the limited understanding coming from currently available energy consumption visualizations. While applications monitoring and communicating energy consumption are common, the use of eco-visualizations to inform about solar energy production is often restricted to screens with numbers and diagrams that show how much energy solar panels produce.

As very few eco-visualization projects have been evaluated [24], it is difficult to estimate their ability to promote sustainable behaviour change in individuals [23]. However, eco-visualizations are likely to have influenced users' attitudes to sustainability, develop users' eco- and energy literacy and triggering awareness and curiosity [23]; all essential criteria for motivating [24] and enabling environmental agency [13]. The first step to knowledge and, ultimately, behaviour change, is awareness and understanding [6], to which end the implementation of digital energy visualizations, especially directed at developing energy literacy of the younger generations, need to be further explored and investigated.

3. Iterative design process

This study followed a design-based research approach [25], using the iterative design process of 'Design Thinking' [26] for the development of innovative concepts for energy visualization. The process can be divided into four phases: *understanding*, *exploration*, *materialization,* and *evaluation*. Through co-creation and a situated understanding of both context and end-user (phases 1-3) a collection of energy visualization concepts was developed, tested, translated into a prototype installed in four pilot schools, and evaluated in a user study (phase 4).

3.1. Phase 1: Understanding

The initial phase focused on getting to know the problem area, building an understanding of the user needs and identifying project challenges as well as frameworks and limitations for the concept development. It included a) analysing *existing energy visualizations*, b) getting to know the *target group* (children aged 9-12 years) and c) developing an understanding of the *school context*.

a) *Existing energy visualizations*. Through a simplified online inventory and utilization of the combined experiences of the project team members, the team built an understanding of existing energy visualization solutions and existing research. Focusing on solutions connected to visualizing and communicating concepts relating to energy, the compiled information from the inventory covered games, product design, and more abstract energy visualizations related to the built environment.

b) *Target group.* A questionnaire survey aimed at school children aged 9-12, with a focus on digital habits, lay the base for an initial understanding of the target group. The questionnaire contained questions about their digital activities, habits, and motivations. It became clear that the children considered interaction and collaboration more stimulating than competitions, and that the time between lessons could be utilized for informal energy education.

c) *Understanding the school environment*. The four schools were selected for a pilot study based on the necessary criteria of having installed and operating solar panels on the school roofs, the staff being open for collaboration and interested in the study, located in different parts Gothenburg and of different typologies (i.e., age and size of buildings, number of pupils, and distribution of classes). For each school, there were different prerequisites for the design of the premises and the schoolyard, as well as the available technology in the school's common areas, and the concept therefore needed to be designed as modular and adaptable. For a better understanding of the school environment and how it was used by the school children, in total 7 site visits were carried out. During the visits the project team talked with staff and children which provided valuable insights into needs, environment, and conditions for how and when energy visualizations could be used and how they best fit into the educational environment. It was important that the visualization was connected to the place where the solar panels were installed, and the starting point was to engage the children during school hours.

The inventory of existing energy visualizations shows that they tend to become complex and data-heavy. At the same time, children have limited previous knowledge of energy systems, which calls for simple, clear, and fun communication solutions, triggering interest and curiosity rather than overloading with facts and data. The process revealed varying levels of understanding of solar energy between different children and schools. A central challenge was for example the difficulty to grasp the abstract energy unit "watt". To reach as many school children as possible and allow them to, the visualization needed to be placed in an area the children visit or pass by daily.

3.2. Phase 2: Exploration

Based on context-specific needs, challenges, and criteria identified in phase 1, the exploration phase explores how an increased understanding and knowledge of solar energy can be approached; by a) making abstract concepts tangible through the b) activation of senses. This iterative phase was carried out as a co-creation process between the project team members and the children from two of the pilot schools, leading to the development of design- and visualization concepts, that were further developed and materialized in phase 3.

a) *Make abstract concepts tangible.* One way to understand abstract concepts is to put them in relation to known concepts, preferably with a connection to the children's everyday lives, such as the lighting of indoor lamps, heating of a house or driving a car.
b) *Activation of senses.* Given the goal of educating future citizens, the means of communication and conveying of information was important. The concept should be easy to relate to, something that engages over time, catch attention on an already busy school day, contains clear facts but also a positive attitude, and contributes to building knowledge of solar energy and a relationship to the unit kilowatt, over time. Solar panels are, in the case of urban built environments, hidden on rooftops, and are not a natural part of the school environment, or of the consciousness of the children. Therefore, the idea for the concept development became to "bring down" the sun or "take down" the solar panels from the roof.

The pedagogical idea of activating multiple senses at the same time for better establishing of knowledge and understanding led to a holistic design concept consisting of three parts: to *feel the sun, taste the sun*, and *see the sun*. To *feel the sun* builds on the principle that movement generates energy, through which an understanding of kilowatt hours can be gained. It can be translated to e.g., physical activities that generate warmth (i.e., thermal energy) or feeling the warmth when the sun hits a body or an object. *Taste the sun* relates to the preparation of food as an energy-consuming activity and the potential of establishing a connection between the school kitchen and locally generated solar energy. *See the sun* is based on the idea of making solar energy visible and therefore comprehensible; through seeing the full spectrum of sunlight as it splits into a rainbow or a yellow line representing solar energy that physically connects to the solar panels on the roof, making their presence known in the schoolyard.

3.3. Phase 3: Materialization

In this phase, design concepts were concretized and realized into SolVis. Prototypes were developed and installed in the four pilot schools to test the concept ideas on the users. The full concept of SolVis (figure 1) consisted of visual and spatial design components for both exterior- and interior spaces, covering a) activities to feel energy, b) design implementations to see energy and c) technical tools to see and to taste energy.

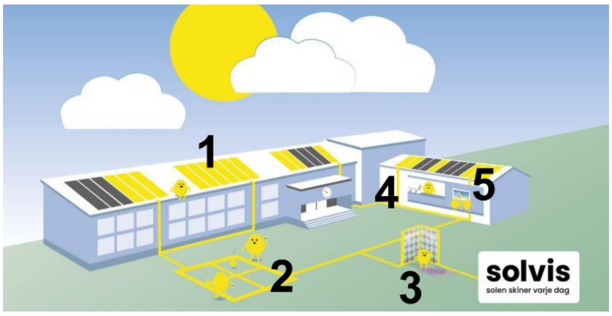

Figure 1. The SolVis holistic concept; visually connecting (1) the solar panels, (2) outdoor movement and play, (3) a sun pavilion, (4) the school kitchen, and (5) the screen, through the yellow line on the ground.

a) *Activities to feel energy.* Yellow pedometers were purchased and distributed at the pilot schools. The idea was for children to use them during breaks, for example when playing outdoor games in the school yard (figure 1), or to measure the total collected energy of organized school activities and compare it to the generated solar energy.

b) *Design implementation to see energy*. To integrate the indoor and outdoor environment a yellow line was implemented, binding together the various SolVis components. The line started at the solar panel and went down to the ground via downpipes, to “harvest” the sun. The line consisted of yellow tape on gutters and facades, and paint for other outdoor markings. The line continued into the school building and finished at a digital screen installed indoors in a central location at the school (figure 2).

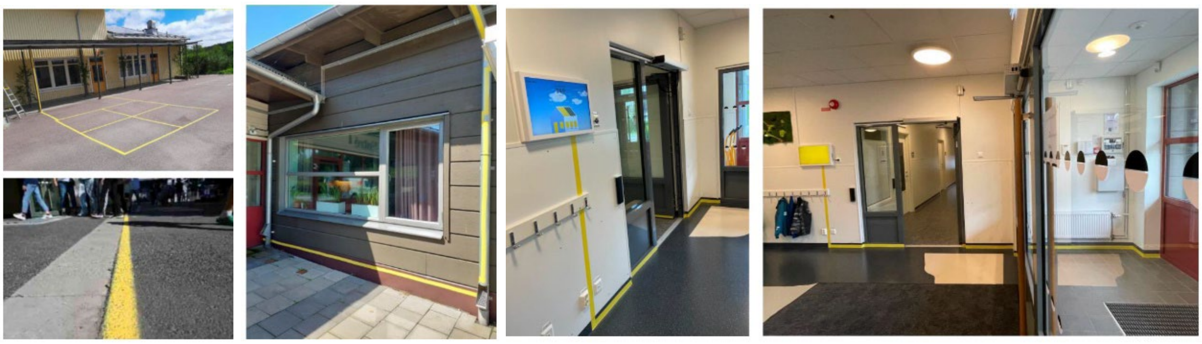

Figure 2. The yellow line outdoors (left) and the yellow line inside the school building leading to the screen (right).

c) *Technical tools to see and to taste energy*. The various parts of the SolVis design concept were brought together in an animation, designed to communicate SolVis to the school children. A screen was placed in an entrance or adjacent to the dining room, where the children naturally pass during a school day. An animation with in total four different examples was displayed, visualizing in a playful and accessible way in real-time the amount of locally produced solar energy. These numbers were set in relation to the energy consumption of previously identified everyday activities. A mascot called Bönan (The Bean) was used for the narrative of the animation. Animation loops visualizing Bönan in different contexts, carrying out various activities were intended to draw the attention of passing children, exemplified in figure 3.

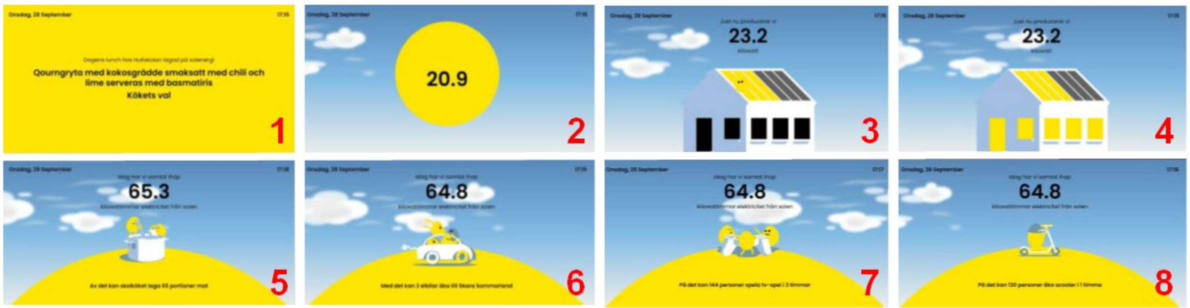

Figure 3. Example of the animation narrative: The yellow background behind the display of today's lunch menu (1) shrinks and becomes a sun, showing the amount of solar electricity being produced in real-time (2). Next, the visualization shows a simplified version of the school building with yellow solar panels on the roof (3), from which the yellow mascot Bönan jumps inside, turning on the lights in the classrooms (4). The animation ends with Bönan performing various energy-consuming activities (5-8), each time indicating how long (time or distance) one can carry out that activity using the total amount of generated electricity.

3.4. Phase 4: User evaluation

The SolVis visualization tools have been evaluated in a user study in several steps, applying both qualitative and quantitative methods for mapping and documenting the user experience. Observations were carried out during the installation of the SolVis screens in two of the schools. The researchers documented the installation process as well as collected initial responses from the pupils. After two months of use, the SolVis visualization prototype was more thoroughly evaluated through a questionnaire survey, focus group discussions, and a new round of observations at all four pilot schools. The evaluations aimed at gaining insight into the tool's pedagogical value (how well does it facilitate knowledge development on energy production and consumption), the effectiveness of its graphics (figures, illustrations, animations), it's design and position (size, height, location, the room configuration, and other spatial elements of its implementation) as well as its technical components.

The survey received 249 responses, of which 233 were from children and the remaining from teachers (9) and other staff (4). The focus group discussions were conducted in individual classes in groups of 15-20 children in ages 9-12. The observations aimed to map pupils' and teachers' movement and behaviour patterns in front of the screen during lunchtime. The group discussions were carried out with both children and teachers in front of the screen and generated more spontaneous and informal feedback than the questionnaire.

The developed and installed digital prototype visualizes in a playful way the solar energy production of the school property in real-time and compares it to the energy consumption of everyday activities, displayed on a centrally placed screen in the school.

4. Result and analysis

From the user evaluation we saw that most respondents appeared to be positive about the screen being installed at their school and liked its content and what they potentially could learn from it. A large majority of the children saw the screen, but many rarely read what was written on it and most of the children stated that they did not learn anything from it.

4.1. Pedagogical value and understanding

From the group discussions in front of the screen, pupils often expressed that they appreciated the displayed information; information about solar panels and energy as well as information about the menu, weather, time and date. Most understood that the screen concerns solar energy, but expressed a limited understanding of energy and kilowatts, as well as the general purpose of the screen; *"No, I know what a solar panel is! But what does the screen do?"* [Pupil]. They asked for more examples of what energy can be used for and how much is needed in a house, with comments such as *"To see how much electricity* *has been used for the month, and maybe even the whole year – that would be very interesting too!"*. As the teachers' own knowledge about solar energy and the content of the screen affected their ability to actively use it as part of the educational activities, it is reasonable to assume that this also affected the pupils' perception of the screen in the long run. Comments from staff included: *"Even teachers wonder what the screen is for and what it shows; the information has not reached out and a lecture or general information would be needed for it to trickle down to the pupils"* [Teacher].

4.2. Content and animations
The evaluation indicates that most users were positive to the screen and found its content stimulating and educational. During installation, some of the pupils were skeptical: *"Can you play Fortnite* [computer game] *on the screen?"* [Pupil]. *"No"* [Project team member]. *"Then it* [the screen] *is bad"* [Pupil]. Many pupils stated that they liked the screen's images and animations, the screen was fun to look at while waiting in line for the cafeteria. The pictures and figures seemed to be popular among all age groups, but especially among the younger children. Many understood that the screen communicates information related to solar energy. *"It's difficult to relate to kilowatts"* [Pupil]. Feedback that the pupils gave about the visualization tool was that it was not entirely easy to interpret the weather and understand how it relates to solar energy. They wanted a clearer connection to the solar panels on the school's roof. Seeing the day's date and the schools lunch menu was something that the pupils appreciated. They expressed a wish for pedagogical entertainment content, such as games or quizzes related to solar energy, and the possibility for the users to interact with the screen, for example, through a touchscreen or buttons.

4.3. Placement and size of the screen
Results show that in some schools the screens may not have been set up in the most effective place. In all schools, the screen was positioned where pupils pass by but not stay, which may play a role in the limited lack of learning from it. Some felt that they did not see it when they entered the room or when they queued for lunch or that it was too high up on the wall. The evaluation indicated that the screen should be larger, or completed with an additional screen somewhere else, closer to the classroom. From this it can be concluded that the placement and design of the screens would need to be reviewed again, but also that the pupils would welcome changes to the design that leads them to see and be able to interact more with the screen, and look at it more often, preferably during breaks. There was a wish for the application to be more interactive and to be used as a pedagogical tool, but that would require placing it in a location where pupils can stop and contemplate the content in a group. Thus, there is a conflict between the screen's current placement in a transit zone and its pedagogical value.

4.4. Future development
There were many ideas on how the animation, content, and screen could be improved. Both children and teachers would like to see more comparisons between energy production and energy use, as well as an introductory film about the solar energy production at the school. The children liked being informed about the weather on the screen, and many said they would also like the outside temperature to be included. Ideas for improvement of the weather visualization came up *"You should add a symbol for weather"* [Installer]. There were several ideas about activity calendars and events to make it more current. The staff was inspired by the tool and proposed a that the tool could include even other types of information related to school activities and the kitchen, for example food waste; *"The possibility to add information about the energy that has been used and lost through food waste (the part food thrown away by the children"* [Other staff].

Further development of SolVis should increase the possibilities for interaction with the tool, show a clearer connection to weather data and outside temperatures, and include more comparisons to relate energy use. an integrated part of the education, meaning development and provision of more instructive material for teachers.

5. Discussion

The SolVis study aims at initiating a process of teaching children, our future adult citizens, to be more energy literate. The research question "How can real-time visualization of solar energy production in learning environments contribute to increased understanding of energy production and consumption?" has been explored. In the following section we discuss the potential of applications like SolVis for facilitating understanding of energy, through the translation of abstract data into tangible and relatable visualizations.

5.1. Education and (informal) learning environments

SolVis' focus on learning environments and children as a target group poses both a challenge and potential. Teaching children at an early age about renewable energy trains them for future, unavoidable challenges related to climate adaptation and mitigation [5,6]. Such developments are crucial in the work against climate anxiety and developing the tools they need and methods to meet climate change in their adult life [18,19]. The school setting is an ideal place to reach out to the younger generations [13,15], educating them about energy and sustainable resource management from an early age. Educating children also a path to educating the overall population through secondary learning of adults outside of the school environment. Such a result is however hard to monitor and confirm [13,18,19].

The visualization tools, digital as well as physical installations in a school environment, need to be developed in close collaboration with the users, i.e., children and teachers early in the process. The SolVis project applied an iterative approach attempting to identify needs, challenges and focus areas early on in collaboration with the school. Still, the evaluation indicated that there are potential conflicts between the pedagogy of the visualization tool and the structure of the school environments, and that the two need to be better synchronized. The use of the SolVis screen is currently inhibited by the rigid structure of the learning environment and its rules about where pupils are permitted to go and when, and the formal divide between learning time and free time.

The idea of SolVis was to reach pupils in an informal learning setting; in-between the classroom and the break, to facilitate self-instructural and informal learning, and a space where children would be able to learn about energy in their own time and under their own conditions. Such an approach is believed to be more efficient in sparking interest and awareness than traditional top-down approaches to learning [4,6,20] and establish schools as a continuous learning environment with innovative approaches to learning [3,7]. As indicated by the evaluation study, however, this specific goal resulted in screens being installed in transitory areas outside the school cafeteria, where pupils spend very little time and are not allowed to spend time during breaks. SolVis evaluation indicates that pupils wanted to be able to interact with the information in their own time – on breaks and in-between classes, and request content that bridges the gap between learning and entertainment through serious games, quizzes, or other interactive elements [20,24].

5.2. Visualization

The energy tools available in today's market often have a risk becoming too advanced and cumbersome for the end user, and when too complicated risk having negative impact on promoting sustainable change [12]. Therefore, SolVis targeted to function in a simple and playful way, as a reminder to the user that the sun contributes with energy daily, intended to be used in the school building or for other day-to-day activities. The visualization of the buildings energy consumption in real-time has not yet been implemented in the prototype. Connecting the two concepts of energy production and energy consumption through real-time data visualization would build awareness of energy as complex and dynamic systems, triggering reflections on the individual's impact on the system as a whole and potentially even contributing to behavioural change. A critical comment from the user evaluation stated: *"Have you developed an application to show electricity, which also runs on electricity? Shouldn't you then show how much it* [the screen] *uses?"* [Pupil]. This indicates that children have started a process of critical thinking about energy use and its connection to their immediate surroundings. It also points to the need for energy visualization tools to expand into a combination of real-time energy production data and interactive energy consumption patterns. The use of energy visualizations in learning environments for children is still a relatively unexplored field, and the SolVis pilot study and the user evaluation study exposes the need for further exploration.

5.3. Scalability
A few pilot studies are not enough to generate change, and the importance of scalability cannot be understated; to truly contribute to the crucial large-scale transition to renewable energy systems, technologies and methods need to be replicable and adjustable between contexts and knowledge fields. The SolVis tool was tailored to suit the specific needs of the local context and target group, but thanks to its modular and adaptable technical solution, it can be implemented in many other contexts; municipalities and property owners who want to implement the concept can replicate the process and technology to fit their needs. With the ambition to implement a future generation of SolVis on all schools in the municipality of Gothenburg, and in developing tools and technologies suitable for this age group, we provide a base material easily transferrable to a more general target group. It is important to establish continuity in learning about renewable energy systems, such as solar energy, over time and to nourish previously gained knowledge through training and application.

5.4. Limitations
Covid 19 had several implications on the project. It was difficult to meet the children and staff during a longer period and the project got delayed. Therefore, not all ideas could be elaborated in depth and translated into a prototype. Also, working in school environments is a challenge. For assistance, we had to rely on staff who had very limited time, and the project time and school vacations did not always match. The delay in the design and installation of the screens resulted in very limited time for evaluation, and for better results evaluation after a longer use of SolVis is needed.

6. Conclusion
In the SolVis study, concepts have been developed for an application for visualization of solar energy in educational environments. The concepts consist of several components, based on the idea that learning is improved through the activation of multiple senses and a contextual understanding of the school environment and local conditions [3] for installation and implementation of new educational tools. The goal was to facilitate increased understanding of sun-generated electricity to children and to provide a basis for further education and development around solar energy.

Based on the evaluation that was made in the project, the potential of SolVis can be confirmed. The concept triggered thoughts and ideas in both pupils and educators, and there was a willingness and potential to learn more about solar energy. Even when failing to fully convey the complex numbers and data of energy to the users, the tool still acted as a trigger or inspiration; in sparking questions and interest, as well as inspiring a demand for further information.

The potential effectiveness of energy visualization tools to influence direct behaviour change is in the case of SolVis further enhanced using the target group; children are more prone to absorb new knowledge than adults, making them an important target group. It can, however, be argued that they are limited in terms of generating direct behavioural change since they are not directly able to influence the energy consumption or production of their immediate surroundings. While this holds true, there are also arguments for children's agency for social and environmental change. Some energy saving efforts can be made by children themselves, and when behaviour change needs to take place in a secondary step, children can use their agency to influence and put pressure on parents, other adults, or those in power of the school environment. Furthermore, through the process of developing *ecological* and *energy literacy*, the evaluation of the SolVis project points to a general increase in the user's awareness of solar energy production and consumption in their local context, and an expressed wish for energy education to be more integrated in the education, both within and between classrooms. It is triggering a process of continued learning, which has the potential to eventually lead to behavioural change.

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