Eco-visualization: an exploration of the concept and its practical implications

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Abstract

Persuasive technologies have the potential to change users' attitudes and behaviors towards more sustainable resource use. Visualizations are important to create awareness of resource use, but to enable users to assess the environmental consequences of their actions, the visualization must relate to the (eco-) systems of which the user is part. The resulting eco-visualizations hold the potential to spur reflections both at the individual, group and societal level. Four examples of eco-visualizations are analyzed and lessons learned are summarized. We found that the successful design of eco-visualizations requires a user centered and iterative approach. We further found that much can be gained by being inspired by works in critical design. In conclusion, we find that eco-visualizations have a strong persuasive potential towards more sustainable resource use and to spur societal debate.

Introduction

Behaviour and attitude changes are needed both at the individual and the societal level to reach the global and local goals of more sustainable resource use [1]. Persuasive Technologies (PT) have a potential to foster these changes as they aim at "changing users' attitudes or behaviors through persuasion and social influence, but not through coercion or deception" [2]. For most products and services, the resource use related to their consumption is not immediately available to the consumer. The first step towards PT for this domain is consequently to make resource use visible in some form. The term *eco-feedback technology* is often used for such systems. In a survey article [3], the authors define *eco-feedback technology* as "technology that provides feedback on individual or group behaviors with a goal of reducing environmental impact" ([3], p.1*)*. Current research indicates that the resource use visualization provided by *eco-feedback technology* alone is not sufficient to create behavior and attitude change, the resource use must also be related to its consequences for the surrounding systems [4;5]. We use the term *eco-visualization* for resource use visualizations with such a systemic focus. We propose the following definition of eco-visualization as a discussion starting point for this special class of persuasive technologies: "Eco-visualization is the dynamic means of revealing the consequences of resource use in order to promote sustainable behavior, decision making and/or attitudes."

In this paper, the definition will be explored further to discuss the potential contribution of eco-visualization in the field of persuasive technologies. The discussion will be strengthened by the use of actual examples from use and development of eco-visualization concepts and prototypes from own research.

ASPECTS OF ECO-VISUALIZATION

Eco-visualization draws on research in a number of areas, relating to various aspects of its design and use. We have identified four such aspects:

1. Eco-visualization technologies: Their form and media of expression.
2. The physical contexts of eco-visualizations: Where they are placed and how they interact with their environment.

3. The social contexts of eco-visualizations: How they become part of the social world, both in real-life and in social media.
4. Eco-visualizations for shaping the future: How they become part of public debate, decision-making processes and political discourses.

ECO-VISUALIZATION TECHNOLOGIES

Even though the information visualization concept builds on the historic tradition of illustrating books – consider for instance monks carefully and skillfully illustrating old scriptures by hand in Medieval monasteries – the visualization concept in computer science was initially limited to computer screens. In fact, it is still mainly associated with novel technologies, such as todays' smart phones-, laptops- and tablets (screens). Furthermore, visualization has long, at least in practice, mainly been used to describe the visual illustration of data, i.e." The use of computer-supported, interactive, visual representations of data to amplify cognition" [6, p6]. However, since its early days, the domain of visualizations has been gradually expanded and is no longer limited to what can be seen, but may, in theory, involve the use of any perception [7]. This is not surprising as the founders of the information visualization concept themselves [6, p7] had already opened up for it to involve other perceptions such as tactile, sounds and scents. This means that even though the use of the visualization concept is still in practice dominated by visual illustration, other perceptions are likely to become more common, either on their own or in combination with visual. Consequently, visualizations are not – nor should they be – limited to the visual.

THE PHYSICAL CONTEXTS OF ECO-VISUALIZATIONS

The visualization concept has been gradually expanded from its initial computer based domain. This expansion is probably, at least partly, a consequence of the more and more seamless introduction of computer technology in everyday life, as predicted already in the 1990s [8]. Furthermore, the continuous development of new technology enables increasingly intriguing and novel means of visualization, based on computer generated information as part of everyday life. Ideally, eco-visualizations will make use of these bits of information, for instance by collecting data from buildings' monitoring systems, and make the data available for those involved in creating the data. Hence, eco-visualizations make the most out of already existing data in everyday life. In this sense, eco-visualizations as persuasive technology uses existing data to help re-connect to the ecosystem, making us aware of systems interdependencies in the built environment. The hidden parts of the city thus become visible for us. This, in itself, potentially has an effect on our perception of our role in this ecosystem. For instance, as part of a pre-study on energy visualization [8], people who moved from the city, out to the countryside felt they became more part of nature and consequently wanted to live more in harmony with it, i.e. preserving resources [9].

THE SOCIAL CONTEXTS OF ECO-VISUALIZATIONS

Another aspect of eco-visualization is its potential use of the increased tendency of people sharing personal information, actions and values via social media. The more or less obligatory use of social media makes personal data increasingly available as we become more accessible and are more seamlessly surrounded by bits of information [9]. Today, the sharing of data via social media has become the reigning norm. This is an example of how the introduction of new technology changes the way we relate to ourselves, our bodies and each other in addition to it changing the way individuals and groups interact with society and its representatives. The technology becomes part of who we are [11]. Consequently, simply letting the technology change us without us reflecting on and taking charge of how it is developed, would be naïve [12].

ECO-VISUALIZATIONS FOR SHAPING THE FUTURE

Potentially, using eco-visualizations stimulates people to take active part in societal debate in addition to the possibility to influence each other to make positive changes to live more sustainable [9]. In short, we are all part of forming technologies which form and change the way we are and relate to each other and the rest of the world. It is in this reality the emerging concept of eco-visualization takes its form. Additionally, in a world where technology develops and changes so easily, we suggest it is a prerequisite that eco-visualizations need to embrace, but not unreflectedly, new technologies (incl. use of monitored/collected data on all levels of society and use of social media as part of the concepts developed).

Examples of eco-visualizations

To inform a discussion about eco-visualization and their use, we present four actual examples from own research.

EXAMPLE 1: THE POWER AWARE CORD

From previous studies, it is known that (energy) visualization concepts – which can be assumed to be true also for eco-visualizations – need to be continually (re-) developed in order to maintain its visualizing effect, i.e. it is necessary to counteract the domestication process which diminishes the effect of any visualization [9]. One way of doing this is to continually develop and embrace new technology and concepts. Hence, even though finding the perfect eco-visualization concept may be possible, it is necessary for it to continually change for it to maintain its effect. Therefore, continuous change is a crucial part of successful eco-visualizations. To exemplify, early stage testing of a fully functioning prototype 'the Power Aware Cord' (PAC) was conducted as part of an iterative design process [9]. The project helped identify three household rationality types in relation to the use of energy (household electricity and heating), namely economy, ecology and technology [9, see also 4], and it [9] also revealed that the PAC with its visual representation – and its lack of numerical representation of the energy use – was provoking for certain household types while it proved fruitful for others depending on the household members energy rationalities. In fact, its very function as actual visualization of energy was questioned by one of the technically oriented households – they did not trust that a device did indeed give rise to stand-by electricity consumption – who ended up buying another energy visualizing device in a hardware store that could confirm the results by giving a numerical representation of the electricity use [9]. This means that the same visualization does not work for all, and, consequently, visualizations need to be personal-

ized [13]. Different household members may well belong to different rationalities and, in addition, the same person may well belong to more than one rationality group. Further more, these rationalities are not consistent, nor consequent as the same person may respond well to one visualization in a certain context and while a different visualization will be more effective in another. [14;15] The process of changing behavior has been broken down into a series of steps in a non-linear process that can iterate back and forth [16]

Further more, as Shove et al. so eloquently has pointed out in their "Theory of Practices", household activities are part of projects that together form our everyday lives [17]. People do not mainly consume resources, but products and services. Hence, the main issue with any visualization is that it eventually becomes more or less invisible, i.e. it disappears into the un-reflected due to the "domestication of technology" [18]. It becomes part of what is known and familiar; the inconspicuous world of what forms our projects of everyday life. This is what happened to the PAC. Its initial visualizing effect disappeared rather quickly (in a matter of weeks), turning it into more of a decorative home appliance. In fact, after some time, some households in the performed study referred to it as a Christmas decoration. The PAC cord is now commercially available via http://www.poweraware.com/ and even though the PAC can be strongly recommended as a thought provoking energy-visualization, it would need to be altered or complemented in order for it to maintain its visualizing effect over time [8]. Hence, it does not – at least on its own – work as a long-term energy- or eco-visualization, though it may well be effective if combined with other strategies for raising awareness of different appliances electricity use.

Previous studies of the effect of energy-visualization (feedback) have also revealed that timing is relevant. The feedback should preferably be given directly when the energy using activity takes place or, in the case of shopping for energy demanding equipment, in connection to the decision to purchase this equipment [19].

EXAMPLE 2: HOUSEHOLD VISUALIZATION IN THE SMART ELECTRICITY GRID

Using the three household rationality types as starting point an explorative study on visualizing data from AMS (automated metering systems), using real time or near real-time data on household electricity use, was performed in cooperation with Demo Steinkjer Living Lab (www.demosteinkjer.no), a national arena for testing and enrollment of smart meters (AMR) and a smart grid system. This study was built on participatory processes and involved low- and high fidelity prototypes, provotypes and concepts to stimulate discussions [20].

The creative processes resulted in highly usable concepts and design ideas, which are currently being further developed (Figure 3). Amongst other, the results revealed a considerable potential in personal electricity use data being communicated as part of a Smart grid, i.e. a socio-technical systemic context. Interestingly, this seemed to work independently of household rationality type.

Furthermore, it does not only matter how much electricity is used at a specific time and place, it needs to be put into a systemic context. In the household electricity domain, this context has at least theoretically become easier to understand and explain with the development of AMS-technology and smart electricity grids in that the data is made available for more accurate and timely planning of distribution and production.

The emergence of smart grids provides a promising context for visualizing the consequences of household electricity use not only to suppliers (those managing smart grids at a systems level). In an explorative study, we provided end users with information on their own electricity use and put it into a "demand and supply" context by providing them with data that is normally only accessed by suppliers. The preliminary findings show that the following visualizations of peak loads in the power grid seem to be relevant to develop and investigate further in creative co-design processes.

Following up on previous studies on "household rationalities" which had pointed out three main rationality types amongst households in relation to the use of electricity, an explorative study using AMR-technology in relation to a Smart Grid (Demo Steinkjer living lab) was performed. This explorative study confirmed the hypothesis that the Security aspect and that of visualizing the household electricity use in a systemic context holds considerable potential to having an influence on attitudes and behavior. The project used provotyping as part of creative workshops.

The results from the first study [20] also indicated it may be more comprehensive for the end users to communicate the systems context if this context – i.e. the systems border – is less ample. Based on this, we have experimented with visualizing

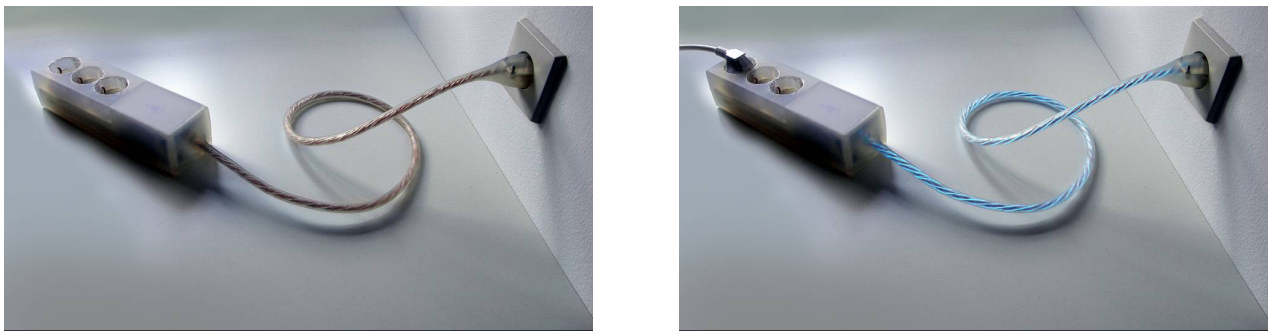

Figure 1 .Power Aware Cord, PAC, developed by the Interactive Institute (www.tii.se). It is a transparent electrical cord with electroluminescent wires molded into it. The left picture (a) shows the core without electric equipment connected to it and the right picture (b) shows the PAC visualizing the power usage represented by the dynamic flow of light through the cord. The higher the power usage is, the faster the flow of light. (Photo: The Interactive Institute.)

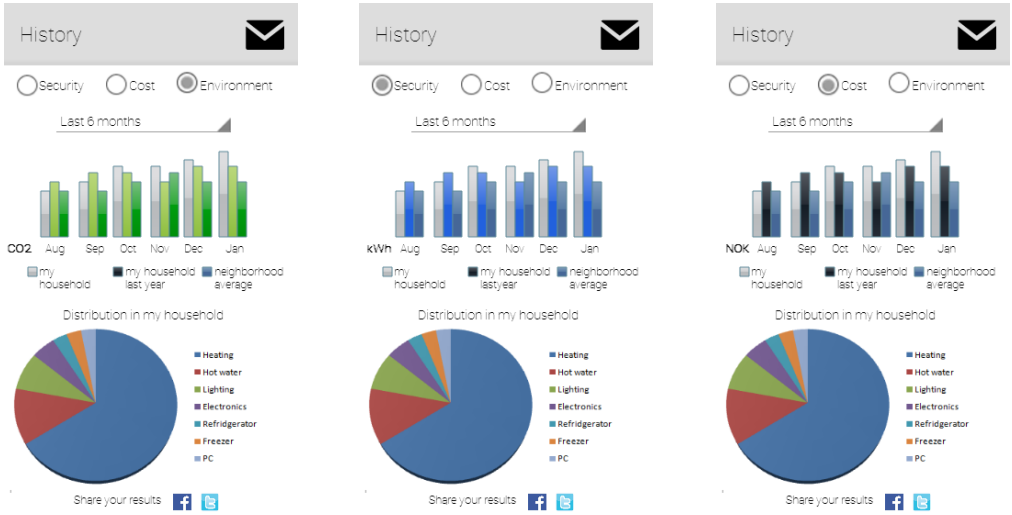

Figure 2 Visualizing household electricity use based on environment, cost or safety/security. (Visualization Tønnesen, in cooperation with the researcher Erica Löfström).

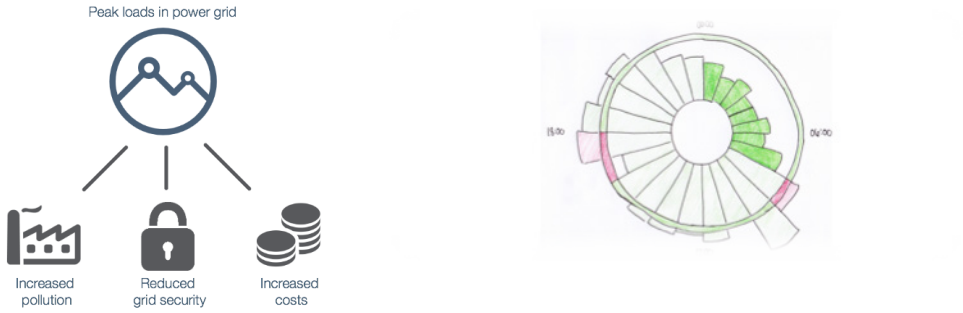

Figure 3. Early stage low-fidelity prototypes visualize use in a systemic context (power grid). Figure 3a (left) shows three different motivation factors for limiting the peak load in a power grid, and Figure 3b (right) visualizes when electricity is the red zones, when we have limited access of power (peak load), and the green zones are ok. The staples illustrate the household electricity use at all times. Only the ones over the max load agreed by the household in advance are red. (Visualizations: Molnes and Voll in cooperation with the researcher Erica Löfström).

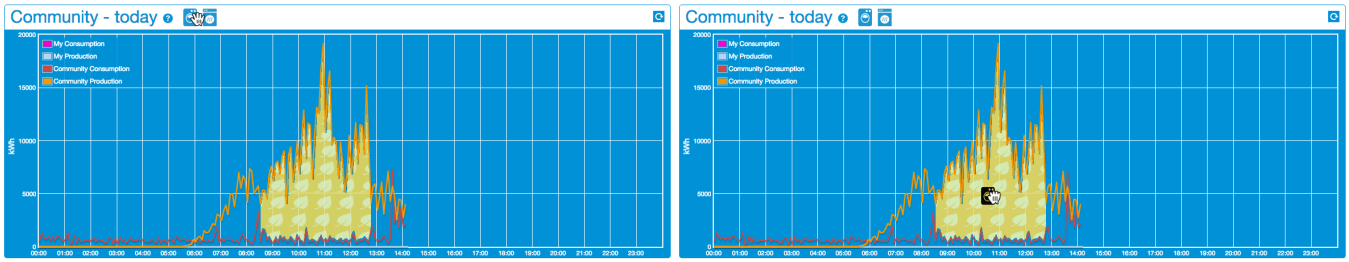

Figure 4. A neighborhood with local production (solar) of electricity enabling flexible use depending on the systems "load". Users can move activities (and use of equipment), to more advantageous times with access to "free energy". This is an animation, seen here in two steps. (Visualization: Franang in cooperation with the researcher Erica Löfström).

household electricity use at a neighborhood level with on site production (Figure 4).

These (Figure 3 and 4) are early attempts, and it is necessary to perform more studies on how to visualize resource use in a systemic context. Also, due to the domestication process, any visualization should be continuously re-developed to maintain its effect.

Co-design and provotyping – participatory processes

One of the success factors of the performed workshops may be inscribed to the use of *provotypes*. Provotypes are short for Provocative Prototypes [21], i.e. prototypes that are intentionally designed to provoke resistance and reflection. If successfully used, these may not only help test the limits to what may be acceptable, but also help speculating on what may be clues to a more sustain-

able future [22]. Provotypes expose and embody tensions that surround a field of interest to support collaborative analysis and collaborative design explorations. Here, the main intent of using provotypes was to stimulate creative processes and discussion.

The examples demonstrate the development of eco-visualization concepts as well suited for extensive user- involvement. The use of the eco-visualization concept, as used here, relates closely to the 'research by design'-tradition, and have, from a methodological aspect, a lot in common with 'Critical Design' and 'Design Noir'[12].

It is hereby suggested that eco-visualization may lie as much or more in the very co-design processes themselves as with the actual eco-visualization techniques [22]. However, the most interesting results from the performed studies on more or less explorative and provocative eco-visualizations is that the successful visualization of the consequences of resource use in a systemic context seems to boost peoples participation in debates at a societal level (see [23]). Hence, potentially it does not only help people make more aware choices of consumption at a personal level, it also makes them more likely to partake in the debates concerning actual decision making processes at a societal level. Arguably, this is where the truly great potential of eco-visualizations in the persuasive technology domain lies. To illustrate, the following quotes are taken from the discussions of the previously mentioned study in cooperation with Demo Steinkjer living lab [20] where end users were provided data on household electricity use in a smart grid context:

- I think it would be a good idea to have a more open approach in relation to information.
- I would suggest we create a society where we actually are playing together, on the same team.
- We are able to draw our own conclusions on this matter. It seems they do not trust us to be smart enough.

EXAMPLE 3: THE ECO-VISUALIZATION TOWER

In another project related to the planning and development of a carbon neutral residential neighborhood, creative workshops were carried out with potential future residents [22]. In this project, the possibility of using public visualizations of the consumption, represented by carbon foot-printing and CO_2 emissions for each household at a neighborhood systemic context, was discussed and a concept of an eco-visualization tower was developed. (Figure 6) Although the concept as such was interesting enough, the most intriguing part of this study was probably related to the, sometimes heated, discussions on whether consumption patterns should be made public, as the consequences of over-consumption actually concern us all at a global level.

The concept of private and public visualization of households consumption data was thoroughly explored in another study as part of the same research project. In this project, *MetKit*, concepts visualizing the Co_2 footprint of consumer goods (prototypes and provotypes) were discussed. The concepts were partly based on solutions developed by the Interactive Institute, a Morally concerned teddy bear, Reflective Surface, and an idea for an app solution to compares different groceries climate footprint (CO_2), and give advice based on this. (Figure 7) Even though the necessary calculations for developing such an app solution did not exist at the time of the study, the possibility of using such a solution was nevertheless vigorously explored in creative co-design workshops [14]. The study also involved provotyping elements such as discussing the possibility of not only the person doing the shopping being presented their own data, but also for it to be visually displayed, for instance by a light signal as part of the persons shopping trolley. Interestingly, the concept of a public display of personal choice was not dismissed as unrealistic or unethical, but resulted in discussions on what should be public and what should be private. Especially in a group of young adults [24] the concept was accepted as a realistic and even positive possibility. The consensus in this group was that "Since my choices have consequences for others, they are not

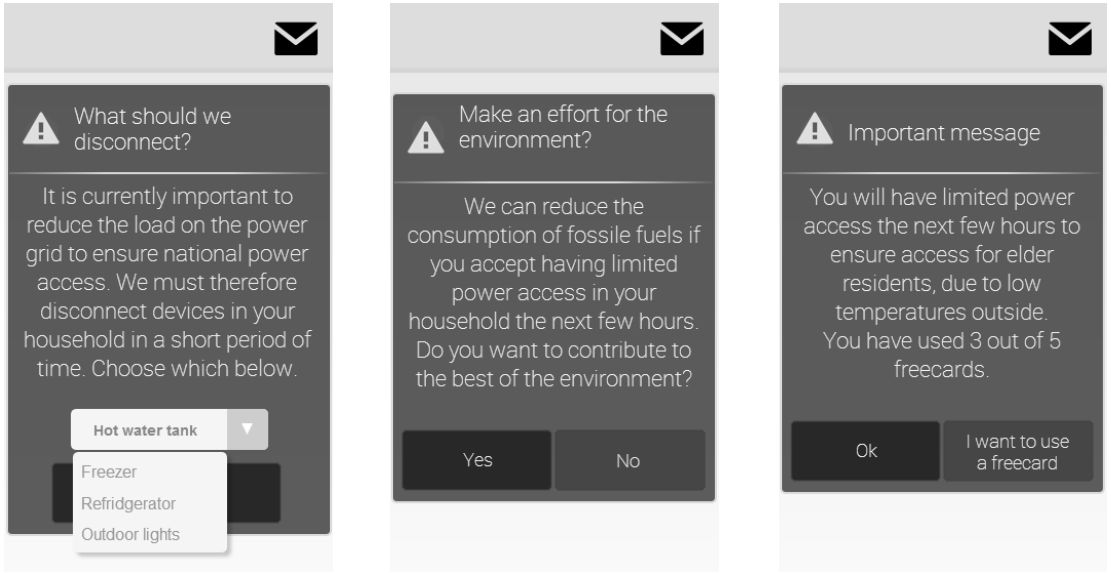

Figure 5 Three different massages communicating consequences of household electricity use. (Visualizations Tønnesen, in cooperation with the researcher Erica Löfström).

Figure 6. The Eco-visualization tower (Illustration: Team SLA, Brøset parallel assignment [24].

only my own business, but concern everyone". Possibly, this is part of a – perhaps necessary – shift of perspective on private consumption and choices as no longer belonging to the personal sphere, but gradually entering the public.

EXAMPLE 4: THE DUCKY APP

Since the explorative study, the calculations tools necessary to be implemented in an app-solutions of the type suggested have been developed. Ducky utilizes such data to visualize the environmental impact of actions taken in everyday life, hence makes it possible to compare the environmental consequences of alternative choices. For doing this, Ducky utilizes reliable calculations on the environmental load of goods and services developed by NTNU Industrial Ecology. (Figure 7).

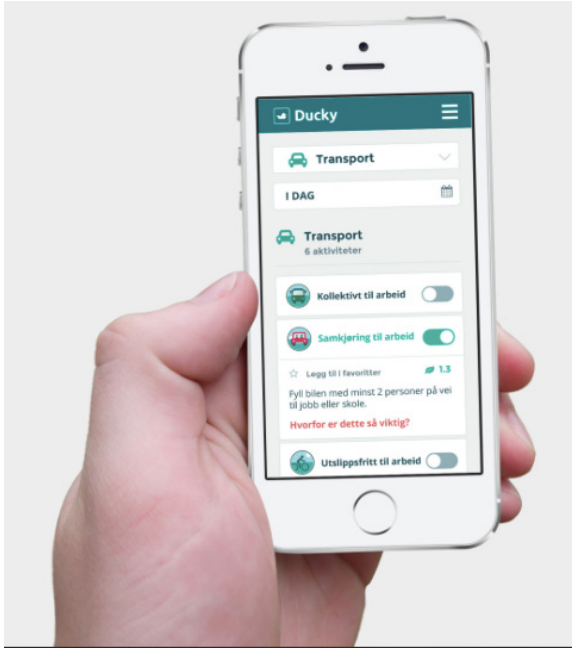

Figure 7. The Ducky app-solution (Photo: www.ducky.no).

Even though the Ducky app does not visualize personal choices to others - unless the person intentionally shares this data – and does not focus on negative aspects of consumption, it is still an interesting eco-visualizing product. Ducky instead focuses on positive changes, which is less risky and provocative. Ducky also uses gaming elements, i.e. you can develop from a hatching egg user to a full-grown duck of different characteristics. Using gaming elements in eco-visualizations has been part of the other (all but the PAC) eco-visualizations used as examples, and the results are encouraging as it has a potential positive effect on the user experience. It also follows as a natural part of developing eco-visualizations to utilize the latest technologies.

Lessons learned from the examples

The four examples covered various aspects of eco-visualization, and raised some issues for further discussion, see Table 1.

Table 1 shows an overview of the four aspects of eco-visualization presented in the introduction for each of the four examples. We see a large variation concerning all four aspects. Concerning technology, two of the examples (2, 4) use traditional screen based technology on off-the-shelf hardware such as smartphones and PC, while two examples (1, 3) use specially made hardware. Concerning physical context, the PAC relates only to the devices connected to the cord, while both the household visualization and the visualization tower relate to the neighborhood. Ducky on the other extreme runs on mobile devices and consequently is independent of physical context as it follows the user wherever he or she goes. The social context varies from private to public. Ducky and the PAC involve mainly the people using them, while the two other examples go beyond the individual. The household visualization is intended for the whole household, and the target group for the visualization tower is the whole neighborhood in which it is placed. All examples spurred discussion and reflections, although on various topics. The PAC provoked a reflection on the need for numeric representation of consumption. The household visualization put the power consumption of the household

Table 1. Aspects of eco-visualization for the four examples.

Example/ Aspect	1: PAC	2: Household visualization	3: Visualization Tower	4: The Ducky app
Technology	Tangible computing	Smartphone and web	Large public displays	Smartphone and web
Physical context	Devices in home or work place	Home and neighbourhood	In a public place in a neighbourhood	Everywhere
Social context	Family/work	Household	Neighbourhood	Private and voluntarily friends/public
Shaping the future/ Discussion	Provokes reflection	Provokes societal debate	Provokes private/ public	Provokes reflections on consequences of action

in relation to the local power grid, and created awareness of the relation between the two. The visualization tower provoked a debate about the (public) nature of private consumption, while Ducky on the other hand provoked reflection for individual users concerning consequences for the environment of choices.

Issues raised by the examples

The four examples raised some interesting issues. These are summed up and discussed here: **Eco-visualizations benefit from embracing new technologies and concepts: The** PAC is an example of new innovative technology. Such technologies potentially draw the attention of the public, thus increase the likelihood of user acceptance. **Eco-visualizations need to be personalized:** The same visualization does not work for all, and, consequently, visualizations need to be personalized. This became evident with the PAC, as the user acceptance was closely linked to the rationality of the user**. Eco-visualization data should be as up-to-date in time as possible:** In general, feedback should preferably be given directly when the resource using activity take place or, in the case of shopping for energy demanding equipment, in connection to the decision to purchase this equipment. The PAC is an example of a technology where the feedback is immediate. **Eco-visualizations benefit from relating data to the (local) socio-technical systemic context:** The household visualization revealed considerable potential in communicated personal electricity use data as part of a Smart grid, i.e. a socio-technical systemic context. Also, the household visualization showed household electricity use at a neighborhood level. This was shown to be more comprehensive for the end users than to relate to larger contexts such as regional- or national. **Designers should be aware that users have different rationalities:** The household visualization worked independently of household rationality type, while for the PAC the user acceptance was closely linked to the rationality of the user. **Eco-visualizations can spur debates on the private nature of consumption:** The visualization tower spurred heated discussions on whether the individual consumer's consumption patterns should or should not be made public, as the consequences of over-consumption actually concern us all at a global level. **Eco-visualizations can benefit from using gaming elements (gamification):** The Ducky example uses gaming elements, i.e. you can develop from a hatching egg user to a full-grown duck of different characteristics.

Discussion

Eco-visualization has at least partly emerged in the cross-cut between art and technology [25]. One advantage of using art as inspiration and cooperation partner is that art has long provided a societal arena for critical reflection and knowledge creation, either directly or more subtly [26]. Therefore, it can be suggested that cooperation with artists of different genres or at least taking inspiration from art contributes positively to the field of eco-visualization. An important aspect of this relatedness to art is that one difference between art and classic science lies in that art does not have any claim of representing something neutral or undisputable. Quite the opposite, it has been claimed that good art is in fact subjective. Hence, different viewers may well have very different, or even opposite, views of what is being communicated through it. This gives us a clue as to how eco-visualization differs from more generic visualization. This difference has to do with the gradual widening of the visualization concept that has taken place.

Today, information visualization is no longer a question of graphic representation – it is used to support the forming of knowledge [27]. This means that it involves the ambition of supporting understanding at a deeper level. It is here suggested that eco-visualization takes this ambition a step further from the initial ambition of illustrating data. The concept of eco-visualisation is also related to critical design, as founded by Dunne and Raby [12], which uses design as a strategy to cultivate what they call critical sensitivity. This involves using design to stimulate critical thinking and people questioning the norms of society. However, while critical design, to express it rather simplistic, aims at the questioning of norms in general, eco-visualization also involves an ambition of change. In congruence with art, eco-visualization is not neutral. It is designed to have an inscribed and more or less outspoken message/direction. However, it may be seen as a response to the now common knowledge that – in a world of ending natural resources – there is a need for more advanced technologies to better manage and reduce resource. In this sense, it is kindred to art as such but

its message or direction is directly linked to the threat of global warming, and to society's ambition to adhere to more able resource use and managements.

We suggest that it operates on the boundary between art and critical design. In relation to this context of more or less continuous economic growth on a planet with finite resources, eco visualization offers a strong potential in providing humans with increased access to information on the choices available, and in providing the tools to manipulate this information, and choices, in meaningful ways. Addressing resource management – potentially at all levels of society – eco-visualization offers a fairly new perspective on the challenges of the transition to more sustainable resource managements. Consequently, we suggest that eco-visualization concepts and designs utilize social media and other technologies to stimulate debate and people to partake in societal debate: *Eco-visualization is not the neutral illustration of data; instead it has direction and is a direct response to the problems of over-consumption of finite natural resources.*

Conclusions

Persuasive technologies have the potential to change users' attitudes and behaviors towards more sustainable resource use. Visualizations are important to create awareness of resource use, but to enable users to assess the environmental consequences of their actions, the visualization must relate to the (eco)systems of which the user is part. We found that the resulting eco-visualizations hold the potential to spur reflections both at the individual, group and societal level. Unfortunately, none of the cases studied were designed to assess long-term effects. Our conclusions are consequently tentative, based on subjective user assessments and short-term use. Further studies are required to assess long-term effects and compare those to our findings.

Four examples of eco-visualizations were analyzed and lessons learned were summarized:

- Eco-visualizations benefit from embracing new technologies and concepts
- Eco-visualizations need to be personalized (enable personalization)
- Eco-visualization data should be as up-to-date in time as possible
- Eco-visualizations benefit from relating the data to the socio-technical systemic context
- Designers of eco-visualizations should be aware that their users have different rationality types.
- Eco-visualizations benefit from relating to a local socio-technical systemic context
- Eco-visualizations can spur debates on the private nature of consumption
- Eco-visualizations can benefit from using gaming elements (gamification)

We found that the successful design of eco-visualizations requires a user-centered and iterative approach. We further found that much can be gained by being inspired by works in digital and interactive art, and critical design. In conclusion we find that eco-visualizations have a strong persuasive potential towards more sustainable resource use and to spur societal debate.

Eco-visualization is a persuasive technology that relates directly to the problems of over-consumption on a planet with finite natural resources. Its aim is to re-connect humans to the eco-system. It is not neutral, and its potential lies as much – if not more – in the development processes that preferably are made in participatory processes involving end users and other relevant stakeholders as in the developed eco-visualization techniques themselves. Further more, it positions itself at the forefront of research as it utilizes novel technologies (which makes continuous development and change part of its very nature) and in addition it tends to position itself in on the border between art and technology. Its inherent ambition is to partake in shaping the future and to influence decision making processes on all levels of society. Based on these aspects, the following and perhaps more ambitious definition of eco-visualization is hereby suggested:

> Communicating (Eco-) system interdependencies with the intent of achieving awareness, flexibility and (societal) debate.

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