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Information Visualization at Home: A literature survey of consumption feedback design

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Abstract. Designing consumption feedback to support sustainable behavior is an active research topic. In recent years, relevant work has suggested a variety of possible design strategies. Addressing the more recent developments in this field, this paper presents a structured literature review, providing an overview of current information design approaches and highlighting open research questions. We suggest a literature-based taxonomy of used strategies, data source and output media with a special focus on design. In particular, we analyze which visual forms are used in current research to reach the identified strategy goals. Our survey reveals that the trend is towards more complex and contextualized feedback and almost every design within sustainable HCI adopts common visualization forms. Furthermore, adopting more advanced visual forms and techniques from information visualization research is helpful when dealing with ever-increasing data sources at home. Yet so far, this combination has often been neglected in feedback design.

1 Introduction

In this decade, sustainable interaction design has become an outstanding trend in Human-Computer-Interaction (HCI) (Blevis, 2007; DiSalvo et al., 2010; Goodman, 2009). In the wake of this trend, consumption feedback (CF), also known as eco-feedback (EF), has been extensively researched as a means of motivating eco-friendly behavioural change. Yet CF can and should not be reduced to a mere component of sustainable HCI (DiSalvo et al., 2010) as it represents an important topic in itself (Froehlich et al., 2010).

CF has a long tradition dating from the first oil crisis in the 1970s. Since that time, environmental psychology has taken an interest in the influence of behavior on energy consumption and has investigated CF as a means of encouraging energy conservation (Brandon and Lewis, 1999). While in the 90s interest waned slightly, research got its second wind this decade through new digital possibilities of smart metering (Darby, 2006). Several meta-analyses within environmental psychology

(Abrahamse et al., 2005; Darby, 2006, 2001; Ehrhardt-Martinez et al., 2010; EPRI, 2009; Fischer, 2007) have demonstrated the positive effect of CF on energy savings.

Originally, feedback design was often quite simple and unsightly. Since then a series of design studies, elaborated guidelines (He et al., 2010; Loviscach, 2011) and suggested frameworks (Björkskog et al., 2010; Fitzpatrick and Smith, 2009; Rodgers and Bartram, 2011) have meant that feedback systems are now more advanced and aesthetically pleasing. Although design-centric surveys of that research have been provided, among others by Pierce et al. (Pierce et al., 2008) and Froehlich et al. (Froehlich, 2011; Froehlich et al., 2010), in light of rapid advances, they are now slightly outdated.

Considering the progress made in design and research, the goal of this paper is twofold: First, to provide an update on the number of new design studies published in recent years. Second, to take a closer look at information design, outlining the lessons learned. From this stance we conduct a systematic literature review (Kim et al., 2010a) that covers the following:

- A literature-based design taxonomy that categorizes current eco-feedback design (Parunak et al., 2004);

- Based on that taxonomy, an overview and summary of existing design strategies, output media, data sources and visual forms;

- Open trends and gaps in current research and thus suggested areas for further research (Kitchenham, 2004).

Our survey extends previous findings and reveals that studies on motivational effects and short-term appropriation of eco-feedback in the home context still dominate sustainable HCI (Froehlich, 2011; van Dam et al., 2010). Our survey shows that novel and innovative design concepts are also identified as the most challenging aspect in current research. Within the studies, we observe a trend towards more advanced solutions including multiple data sources, data pre-processing and mobile, cross-device feedback with a special focus on design. In particular, interactive and context-aware feedback have become more popular.

Despite the existing trend towards more complex and holistic solutions of eco-feedback with a design based focus, we were surprised to uncover that a link to the existing information visualization (InfoVis) (Card et al., 1999) discipline, which deals with methods and techniques for complex data visualization, is relatively weak. Almost every design within sustainable HCI adopts simple and common visualization forms that are also a subject of research in InfoVis (e.g. Bar-, Line- or Gauge-Charts), but without explicit references. That missing link might be a reason why sustainable HCI is currently neglecting a more systematic adoption of analytical and design techniques developed in time-oriented InfoVis research (Aigner et al., 2011; Card et al., 1999; Shneiderman, 1996).

In conclusion, we believe that sustainable HCI would benefit from eco-information visualization (Aigner et al., 2011) as the next step towards increasing the information value of metering data at home and beyond.

2 Related Work

2.1 Research Outside HCI

Studies on eco-feedback have a long tradition, especially in environmental psychology. The primary research question here is to evaluate if and to what extent eco-feedback has an effect on people's individual motivation and actual behavior. To answer this question, controlled experiments are ordinarily conducted, with feedback as the independent and behavioral change as the dependent variable. Literature reviews echo this research design. On the whole, surveys are meta-analyses (Crombie and Davies, n.d.) that contrast and combine results from different studies to identify patterns or disagreements among study results and other insights gained by comparing multiple studies. An illustrative example is the much-cited review by Abrahamse et al. (Abrahamse et al., 2005), focusing on the effectiveness of different interventions strategies including eco-feedback.

A more design-oriented survey was conducted by Darby (Darby, 2001), who reviewed research from 1975 and 2000. She developed a taxonomy of feedback types, aiming to obtain a more detailed understanding of the relationship between feedback and behavioral change. On an abstract level, she simply distinguishes between direct and indirect feedback as the two main groups; on a more fine-grained level, she distinguishes basic metering, key meters, direct displays, TV or PC feedback, disaggregated feedback and ambient displays as forms of feedback. Darby extracted best practices from the literature, concluding that feedback works best when it is accessible, attractive and clear. An update published in 2006 (Darby, 2006) includes dynamic tariffs as an additional factor. In a similar fashion, Fischer (Fischer, 2007) reviews studies from 1987 to 2007, asking which kind of feedback is the most successful. She developed a taxonomy of feedback attributes that might have an impact. Her survey suggests that an ideal design does not seem to exist, even though frequently given feedback and allowing user interaction seem to be key success factors.

A detailed review over the long span of 23 years (1974-2010) is provided by Ehrhardt-Martinez et al. (Ehrhardt-Martinez et al., 2010), who cover not only direct and indirect feedback in the residential sector but automation systems too. Focusing on the impact on energy savings, they compare smart feedback with other types of feedback such as enhanced billing, estimated feedback, daily/weekly feedback, aggregated real-time feedback, disaggregated real-time feedback and different motivational elements such as goal-setting, competition

and social norms. They further use cross-tabs to find dependencies and synergies. For instance, they uncover that real-time plus feedback tends to generate the highest saving among the feedback types but that the feedback has to work together with other factors.

Another, more recent, survey is the EPRI study (EPRI, 2009), reviewing studies from 1978 to 2009. That survey merits mentioning as it also outlines blind spots where further research is required, e.g. participation, feedback delivery mechanism, persistence of feedback, dynamic pricing and demographic considerations.

2.2 Research Within HCI

In comparison to environmental psychology, HCI is a relatively multi-disciplinary research area with a stronger design focus (Carroll, 1997). It is therefore not surprising that eco-feedback research within HCI has a slightly different focus, as outlined by Froehlich et al.: “The difference between the HCI and the environmental psychology literature is the emphasis (or lack of emphasis) on the visual design of the eco-feedback interface itself” (Froehlich et al., 2010). In particular, a rich corpus of design studies exists in HCI that - among others - explores the design space and realizes novel concepts. DiSalvo et al.’s survey (DiSalvo et al., 2010) shows that – for better or worse – by far the most design studies are concerned with CF based on persuasive technology. They are supplemented by guidelines, frameworks and design space analysis (Froehlich, 2011).

He et al. (He et al., 2010), for instance, outline a catalogue of design guidelines with regard to designing tailored feedback. Loviscach (Loviscach, 2011) explore the design space as related to personal energy conservation assistants distinguishing between feedback, advice and automation. Fitzpatrick et al. (Fitzpatrick and Smith, 2009) outline basic CF-features. Björkskog et al. (Björkskog et al., 2010) provide a seven-dimensional feature matrix for conducting market surveys. They further elaborate a generic three-layer architecture, with a sensing, a service and an application layer, to realize energy awareness systems. Rodgers and Bartram (Rodgers and Bartram, 2010) suggest a five-dimensional framework for analysing and designing CF, with a special focus on eco-feedback.

In addition to these theory-driven and experience-based design guidelines, a few reviews exist that use the literature review methodology to explore the design space and common design practices. Pierce et al. (Pierce et al., 2008), for instance, survey diverse studies on eco-visualization, with a special focus on design strategies. They split the complex into three parts: feedback covering data and visualization; context of use, taking the axes dweller and third-party control into account, and strategies for designing effective visualizations. Each strategy is discussed and illustrated by examples.

Another notable survey is by Froehlich (Froehlich, 2011), who reviews 44 papers from HCI and 12 from environmental psychology ranging from 1976 to 2009. His review is divided in two parts: One deals with the differences between environmental psychology and HCI while the other reviews the design space for eco-feedback. From the comparative analysis, eight dimensions emerge that feedback design should consider. These include motivational strategies, display medium and data representation.

In summary, the existing surveys on CF, design guidelines and elaborated frameworks (Björkskog et al., 2010; Darby, 2006, 2001; Ehrhardt-Martinez et al., 2010; EPRI, 2009; Fischer, 2007; Fitzpatrick and Smith, 2009; Froehlich, 2011; He et al., 2010; Loviscach, 2011; Pierce et al., 2008; Rodgers and Bartram, 2010) provide good information for the design of eco-feedback systems. However, a systematic review focusing on design from recent years is missing and therefore newly emerged or improved concepts are neglected. In this regard, this survey provides a much-needed update and furthermore a literature-based analysis of the information design of the various solutions.

3 Methodology

To provide such an overview of current information design approaches and to show open research questions and areas, we apply a common methodical proceeding of literature reviews (Biolchini et al., 2005; Kitchenham, 2004).

Scope and period: The review scope was informed by our research goal to uncover trends and patterns in modern CF design. Other reviews (EPRI, 2009; Fischer, 2007; Froehlich, 2011; Pierce et al., 2008) have addressed this goal in part, although the period of those reviews ended, at the latest, in 2010-2011.

In our review, we therefore focus on the period from 2009-2015. Our research question guided our selection of keywords and libraries for our systematic review. We used the following digital libraries for our literature search: ACM Digital Library¹, IEEEExplore Digital Library² and Google Scholar³, arguably covering the most popular sources of HCI literature.

As there is no unique nomenclature, we also used synonyms and related terms as search keywords. We used the follow keywords: “*HEMS*”, “*eco feedback*”, “*energy visualization*”, “*energy monitoring*”, “*energy feedback*”, “*consumption feedback*”, “*consumption monitoring*”, “*domestic energy*” AND YEAR > 2009

Exclusion and Inclusion Criteria: The manifold studies we found using these keywords made us define several criteria for including studies into or excluding studies from the review. Inclusion criteria included a contribution having been

¹ <http://dl.acm.org/> (01.06.2018)

² <http://ieeexplore.ieee.org/Xplore/home.jsp> (01.06.2018)

³ <http://scholar.google.de/> (01.06.2018)

peer reviewed, being available online and being written in English. Other selective criteria included a very rough thematic selection by title and abstract and by skimming over the text and whether it was positioned within HCI.

After this pre-selection, we carefully read the remaining papers and refined our inclusion criteria to the following:

- Established in the home-context
- Consists of a CF prototype or final product

We then divided the results into two categories. The first included all the studies in which the CF system was used in a real-world field study and was evaluated by households. The other category included the papers in which CF systems were developed and evaluated in a lab or by other methods.

Data extraction: In the next step, information from studies was extracted in a standardized way (Biolchini et al., 2005), culminating in over 250 pages of extraction forms: From each paper, we first collected general information. Additionally, we collected information about the data sources, covering data collection, storage and granularity. We studied how the data layer, data processing, and presentation layer were realized in terms of display, feedback type applied, general design patterns and design elements used. In the studies with field trials, we collected additional data about the participants, the method of the study and the prototype evaluation process.

Literature: Our final corpus consisted of 68 papers (see chapters 4 and 5) with 62 different eco-feedback systems. The studies took place in different countries, for example in England, Sweden, Finland, Italy, Denmark, Portugal, the United States of America, China and Australia

4 Outlining a Design Taxonomy

As existing research in CF needed to be structured for the analysis, we searched first for a suitable categorization strategy that could be apply in our analysis.

This initial search revealed a broad mass of wide-ranging approaches to the topic. The literature contains several strategies and frameworks for classifying CF systems. These range from a simple method of distinguishing between direct and indirect feedback (Darby, 2006, 2001) to more refined methods using a fine-grained classification (EPRI, 2009), a feature matrix (Björkskog et al., 2010) or an elaborate, multi-dimensional design-space (Froehlich, 2011; Rodgers and Bartram, 2010). Each method has its own particular advantages, but since design is becoming increasingly complex, more specific methods are needed.

Our aim was to provide a literature-based taxonomy that covers the design aspect in more detail and allows a holistic view of the connections between different parts of design. We therefore considered the commonly used design strategies as the major design-driving factor and extended this factor by adopting

an informative design-centric view informed by Card et al.'s information visualization reference model (Card et al., 1999) to take well-known design

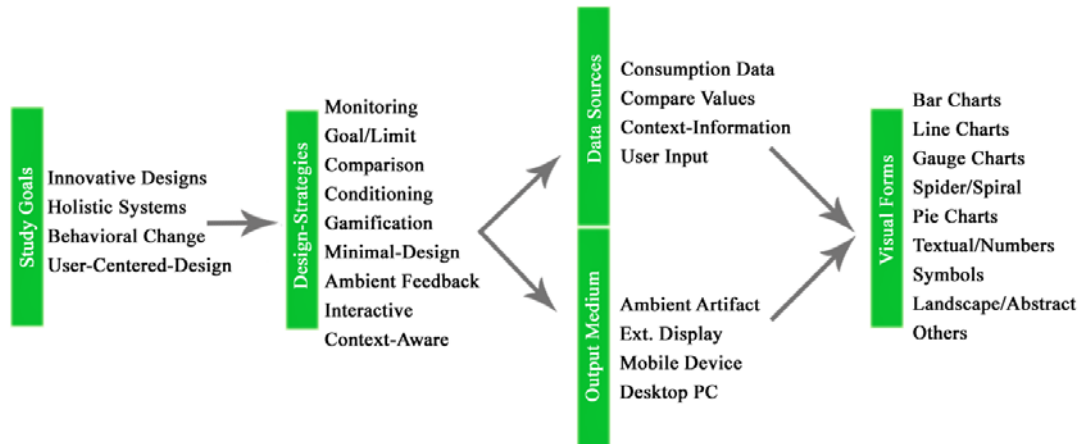


Figure 1. Literature-based design taxonomy for eco-feedback systems

techniques and methods into account. From this stance, we studied in detail which *data sources*, which *media* and which *visual forms* are commonly used in the literature to shape the overall design concept and design objectives (Figure 1).

5 Survey of Consumption Feedback Technology

We used the identified taxonomy to focus more explicitly on studies of CF within HCI literature (cf. Figure 1). In the following, we go through each taxonomy category systematically, describing the implementations and characteristics of the individual elements from the past few years in eco-feedback research.

5.1 Study Goals and Contribution

First, we analyzed and uncovered existing objectives and goals from the wide range of studies. In particular, we looked at what the authors claimed to be their contributions and research interests. As a result, we were able to identify four major non-exclusive types of study goal and contributions.

5.1.1 Novel and Innovative Design Concepts

The biggest group claimed new design concepts (Banerjee, 2013; Banerjee et al., 2011; Broms et al., 2010; Chao et al., 2010; Costanza et al., 2012; Gamberini et al., 2011; Grevet et al., 2010; Guo et al., 2013; Gustafsson et al., 2009b; Gustafsson and Gyllenswärd, 2005; Heller and Borchers, 2011; Jain et al., 2012; Kugler et al., 2011; T. Liu et al., 2013; Maan et al., 2010; Madeira et al., 2011;

Monigatti et al., 2010; Odom et al., 2008; Petersen et al., 2009; Petkov et al., 2011b; Weiss et al., 2009, 2011) or systems that “go beyond past examples” (Grevet et al., 2010). The goal of these design concepts is to extend the state of the art of CF design by novel features and functions. Some design approaches address a new usage scenario in the home context, such as pricing models, dormitories or Off-Grid homes (e.g. (Kugler et al., 2011; T. Liu et al., 2013; Monigatti et al., 2010)); others focus on new single design elements (e.g. a practice view that allows users to compare what-if scenarios) (Costanza et al., 2012; Jain et al., 2012; Madeira et al., 2011; Petersen et al., 2009) and some use new techniques in their CF systems such as integrating one-dimensional and multi-dimensional comparative feedback in one application (e.g. (Chao et al., 2010; Grevet et al., 2010)).

5.1.2 Holistic Systems / Infrastructural Issues

In contrast to the first group, there were also a large number of studies that focus on a holistic approach for designing CF systems and less on specific design elements and functionalities (e.g. (Choi et al., 2011; Kaliappan et al., 2012; Kunold et al., 2011; Leppänen et al., 2012; Nuno Jardim Nunes, 2011; Pereira et al., 2012)). This type of study focuses more on hardware and infrastructural issues of CF technology, including new concepts of home automation and low-cost solutions (e.g. (Banerjee et al., 2011; Nuno Jardim Nunes, 2011)).

5.1.3 Behavioral Change

Studies in this group examine how people use the eco-feedback system to change their energy-related behavior (e.g. (Kjeldskov et al., 2012; Petkov et al., 2012, 2011a; Selvefors et al., 2013; van Dam et al., 2010; Yun, 2009)). The studies focus on persuasive technology to change user behavior and “to investigate if, and how, people use the systems” (Selvefors et al., 2013). This category is highly inspired by Fogg’s behavioral model (Fogg, 2009).

5.1.4 User-Centered Design

A few studies (e.g. (Petkov et al., 2012, 2011a; van Dam et al., 2010)) go even further, emphasizing the importance of considering individuals user’s or user group’s needs. The key conclusion here is that “a one-size fits-all approach for home energy monitors cannot be justified“ (van Dam et al., 2010).

5.2 Design Strategies

Second, we analyzed the existing research regarding the type of design strategies applied as an important characteristic within the design process (Froehlich, 2011; Froehlich et al., 2010; Pierce et al., 2008; Rodgers and Bartram, 2011).

Our survey revealed that strategies are not mutually exclusive and boundaries are blurred. Moreover, we uncovered two main clusters of strategies: *motivation-centric strategies* including goal-setting, comparison, conditionals and gamification and *design-centric strategies* including monitoring, minimal design and ambient and interactive feedback, which focuses more on how to visualize the information. In the following, we describe the implementation of each strategy in more detail.

5.2.1 Monitoring

Monitoring aims to inform users as precisely and accurately as possible about their consumption. This strategy relies on the information deficit hypothesis that feedback fills an "information vacuum": Additional consumption information increases awareness or knowledge about both household consumption and individual appliances, which incentivize consumers to use less energy (Wilhite and Ling, 1995).

Addressing the rational consumer, the design is typically sober and clear. Users should be supported in making informed decisions concerning current consumption (e.g. via direct feedback) or future consumption (e.g. by providing a forecast and return of investment calculation). Monitoring is widely seen as a basic feature, such that it is available in nearly every system reviewed.

5.2.2 Comparison

People use various forms of comparison to make energy consumption accountable (Schwartz et al., 2013b). The most important forms are normative and social comparison: Normative comparison is used to compare a consumer's own present and past consumption (Jain et al., 2012) while social comparison is about comparing oneself with others. A further comparison is that between individual vs. individual and individual vs. group comparison (Grevet et al., 2010).

Most studies focus on social comparison, the major challenge of which is to ensure the comparability of the compared categories and to consider household context (e.g. the number of adults/children in a household or the size of living space should be the same) (Grevet et al., 2010; Jain et al., 2012; Kjeldskov et al., 2012; Q. Liu et al., 2013; Petkov et al., 2011a; Quintal et al., 2010; Sundramoorthy et al., 2010). Mostly, comparison data is simply integrated into standard monitoring visualizations (e.g. (Jain et al., 2012; Petkov et al., 2011a)). Some social comparison approaches integrate their information into social media platforms such as Facebook (Foster et al., 2010; Q. Liu et al., 2013).

User preferences are diverse: some like comparison with people they know while others prefer large user groups (Petkov et al., 2011b); others prefer benchmarking with a known average (Petkov et al., 2011a) and wish to remain anonymous (Grevet et al., 2010); others object to everything as they feel their particular life-situation is not comparable (Schwartz et al., 2013b) to others or

they feel demotivated when others are constantly “better” (Jacucci et al., 2009). These factors make normative feedback appear preferable (Q. Liu et al., 2013), although others report that social comparisons are reasonably effective (Grevet et al., 2010). These mixed findings make universal recommendations difficult and indicate that user satisfaction and design effectiveness (measured in energy savings) should be treated as two independent factors.

5.2.3 Goal-setting

In environmental psychology, goal-setting is a well-known strategy for promoting energy conservation (Abrahamse et al., 2005). It is defined as making a desire explicit to reach a certain future state (Jacucci et al., 2009). There are various ways to implement goal-setting features (Crowley et al., 2011; Jacucci et al., 2009; Kjeldskov et al., 2012; Kugler et al., 2011; T. Liu et al., 2013). For instance, Kugler et al. (Kugler et al., 2011) allow limits to be set by usage – i.e. maximum consumed energy in a given period or for a fixed amount of money – that should not be exceeded or undershot. EnergyLife (Jacucci et al., 2009) use goals and sub-goals as part of a gamification strategy, whereby a particular goal must be attained to access a higher level. In addition, lights are dimmed as an ambient signal that a goal has not been reached. T. Liu et al. (T. Liu et al., 2013) discuss prepaid electricity tariffs as a special form of goal-setting that ensures a pre-defined limit is not exceeded. However, to prevent such strict power cut offs, T. Liu et al. (T. Liu et al., 2013) allowed users to set a limit before their credit expired. Critical design issues cover goal-definition, whereby a good heuristic seems to rest on earlier periods (e.g. use 2% less than last week) (Crowley et al., 2011). A further issue relates to the kind of feedback (positive or negative) and when it is given. Here, guidelines – such as providing a continuous reminder (Kjeldskov et al., 2012) – are close to those outlined for designing conditioning (e.g. rewards or penalties (Froehlich et al., 2010)).

5.2.4 Conditioning

Conditioning refers to using incentives/disincentives and rewards/penalties to motivate pro-environmental behavior. A good example of a social punishment is given by Foster et al. (Foster et al., 2011): When a user saves too little, a random embarrassing song is posted on the user's Facebook wall. An example of conditioning strategy focusing on learning is given in Cowan et al. (Cowan et al., 2013): When a user boils too much water, the kettle stops working until it is filled with the right amount of water. The various forms of conditioning are discussed by Froehlich et al. (Froehlich, 2011; Froehlich et al., 2010) in more detail. Overall, conditioning seems to work well for some users, but not for all (Kirman et al., 2010). Some users note that negative messages motivate them while others simply get frustrated (Kjeldskov et al., 2012). An alternative is only to reward

good behavior (Quintal et al., 2010). Also, using humor seems to be a strategy that frustrates users less (Foster et al., 2011).

5.2.5 Gamification

Gamification has become popular in recent years. In a broad sense, it refers to using motivational, competitive elements known from games, including goal-setting, social comparison and conditions. In this section, we use a narrower view, looking only at single and multi-player games.

The Tamagotchi genre presents a popular single-player gamification strategy in which a digital avatar is influenced by energy consumption (Gustafsson et al., 2009a). In single-player games, users can archive rewards and earn scores by energy savings and quizzes (Gamberini et al., 2011; Jacucci et al., 2009; Jain et al., 2012; Madeira et al., 2011).

Multi-player gamification usually adopts the quest genre, often supplemented by rankings. A connection to social comparison can be recognized here, ensuring that participation and the comparison between several people motivates efficient behavior. Furthermore, commenting on each other was highlighted as a fun-enhancing feature to increase motivation and intensity of usage (Foster et al., 2010; Petkov et al., 2011a). In general, users can play against each other, but team challenges are also popular, in which families, friends etc. have to reach a common goal (Crowley et al., 2011; Grevet et al., 2010; Gustafsson et al., 2009b). Quests can take various forms but are typically related to energy conservation, e.g. reducing lighting one day or heating on another (Gustafsson et al., 2009b). Game design is generally faced with undesired cheating effects. Gustafsson et al. (Gustafsson et al., 2009b) report that, when a quest only determines specific time-slots (e.g. 8 a.m. – 10 p.m.), some users start to wash at night to win the quest.

Concerning user satisfaction, challenges seem to be well rated (Madeira et al., 2011) but preferred more by experienced energy users (Petkov et al., 2011a). Also ranking is rated positively (Foster et al., 2010), especially if the 'opponents' are known (Petkov et al., 2011b). Instead of just providing a ranking list, Kjeldskov et al. and Petkov et al. (Kjeldskov et al., 2012; Petkov et al., 2011a) suggest that ratings should provide feedback on whether a user's consumption is high, low or medium.

5.2.6 Minimal Design

Minimal design aims to provide less information which is easy to understand and most relevant for the user context (van Dam et al., 2010; Yun, 2009). Even this small portion of information can still be effective – especially as the information is enriched by people's interpretation (Yun, 2009).

Comparing lights and numbers as a feedback form Mann et al. (Maan et al., 2010) further show that the minimal light design is suitable for giving quick feedback. It causes only a small cognitive load (in comparison to visual

information such as numbers) and users are less distracted because no direct action is necessary to inform oneself.

5.2.7 Ambient Feedback

Ambient feedback is characterized as “abstract and aesthetic peripheral displays” (Mankoff et al., 2003) that are set at the periphery of a user’s attention. Ambient feedback is often minimal and realized by extra artifacts; other output mediums are even generally possible (Kim et al., 2010b). Visualizations are either abstract, e.g. colors (Monigatti et al., 2010), or naturalistic, e.g. showing the “destruction of nature” (Kim et al., 2010b; Nisi et al., 2013; Rodgers and Bartram, 2011).

Ambient feedback counts as being easy to understand (Nisi et al., 2013; Rodgers and Bartram, 2011). The design must, however, be unobtrusive, minimal and only subconsciously noticeable (Maan et al., 2010; Rodgers and Bartram, 2011). Hence, a general design tradeoff must be made between unobtrusiveness and attracting attention. For instance, a “dramatic” change helps to touch people emotionally (Nisi et al., 2013); by the same token, it could lead to stress and guilt (Kim et al., 2010b). Abstract forms are easier to design and also seem to be preferred over natural ones (Rodgers and Bartram, 2011).

Another tradeoff relates to the amount of feedback information. There is a tendency to provide additional information, especially if the user is already energy conscious (Kim et al., 2010b; Nisi et al., 2013). However, care must be taken not to destroy the overall design. The right design also seems to depend on the type of user, e.g. Malkonin et al. (Makonin et al., 2012) report that busy people prefer simple feedback, younger people prefer bright colors and older people prefer dark colors.

5.2.8 Interactive Feedback

Interactive feedback is defined as feedback that implies a proactive action by the user to generate energy information that is more valuable to the user. This strategy covers e.g. tagging, whereby users can tag or add events directly in a time graph (Costanza et al., 2012; Gustafsson et al., 2009b). Tagging helps users to link energy consumption to something understandable (such as activities or special events) (Gustafsson et al., 2009b). One variant allows users to define groups aggregating individual consumers at room-level or with regard to their purposes (e.g. entertainment, cooking, etc.) (Schwartz et al., 2013a). Another interactive feature suggested by both Jain et al. (Jain et al., 2012) and Weiss et al. (Weiss et al., 2011) is active measuring. This feature allows users to record time-periods e.g. to uncover the consumption of specific devices (e.g. switching a light on/off) or specific actions (e.g. making coffee). It improves the breakdown of consumption, making use of user’s context knowledge, while for the users it is playful and increases the perceived control (Jain et al., 2012; Weiss et al., 2011).

Another feature discussed by Jain et al. (Jain et al., 2012) is active comparison, whereby users add their energy consumption data manually to compare it with that of other people or other devices.

As feedback grows more complex and becomes part of complete home control systems (Chao et al., 2010; Jakobi et al., 2017), it seems that interactive features such as tagging, configuring or active measuring will become more important in the future. However, as the corpus of studies is still small, it is currently difficult to outline best practices.

5.2.9 Context-aware Feedback

Context-aware feedback gathers additional information to enrich consumption information, e.g. a user's position or activities. The most commonly used context-information is the location of the user/users, e.g. using RFID (Guo et al., 2013), doorway sensors (Lee et al., 2014) or WiFi-fingerprinting (Castelli et al., 2014a). This information allows the interface of mobile devices to be adapted, showing the consumers only in their direct surroundings (Jahn et al., 2010). Castelli et al. (Castelli et al., 2014a) demonstrate how user location can be used to alert to current wastage outside the room; furthermore, the percentage of used energy is shown in the historical feedback, when no one was in the room. Neustaedter et al. (Neustaedter et al., 2013) use personal calendars as an additional source to enrich the feedback. This connection helps users to link the data to activities when reflecting on past consumption. Kjeldskov et al. (Kjeldskov et al., 2015) use additional information to forecast energy prices, to enable users to plan their consumption.

As context-aware feedback is relatively new, little is known about its effectiveness on saving, learning and user satisfaction.

5.3 Data Sources

The third category describes the kind of *data sources*, which play an important role in information design. The primary sources used in the literature are fine-grained consumption data about the total household (collected e.g. by Smart Meters) or individual consumers (collected e.g. by Smart Plugs). More modern energy management systems also integrate multiples of these sources. This combination provides new opportunities, e.g. for comparative design but also makes the design more complex, and the risk of information overload increases when too many sources are available (Jacucci et al., 2009).

We also observed a trend to include further data sources including comparative values from other households or statistical data on average consumption (Sundramoorthy et al., 2010), user input to tag, aggregate or break down consumers and context-information about the users, e.g. their presence (Castelli et al., 2014b) or their activities based on calendar entries (Neustaedter et al., 2013).

Some studies additionally make use of current and forecast data for weather, electricity, price, date etc., but so far these are generally found in the area of home control (Reinisch et al., 2011; Zhang et al., 2008).

Overall, metering data serves as the basis for all CF design. From a visual stance, it presents a time-oriented data source with special characteristics: *linear time* (Aigner et al., 2011) from past to future; and also *cyclic organization* (Aigner et al., 2011), composed of a finite set of recurring time elements (days, weeks, months etc.). Linear time models are mostly used, with few exceptions (such as the Energy Clock (Broms et al., 2010)) that make use of the *cyclic* organization to visualize consumption patterns and rhythms.

The visual design must further decide if time series should be presented as *point-based* or as *interval-based* values (Aigner et al., 2011), providing information over subsections in time. Related to this is the *updated rate* (Aigner et al., 2011), ranging from nearly real-time to seldom, irregular updates. In addition, when dealing with time, it has proven helpful to consider different level of abstraction using different *granularities* (seconds, minutes, hours, etc.) (Aigner et al., 2011). Most studies rely on fine-grained updates ranging from every minute, every 10 minutes, every 15 minutes or hourly. This data is mostly used to calculate higher granularities, such as days, weeks etc.

Consumption could further be viewed as an *abstract entity* (Aigner et al., 2011) not connected to space or place or in combination with additional data as *spatial* (Aigner et al., 2011) (e.g. taking the location of consumers into account). Furthermore, it matters if we are dealing with *univariate data*, where each time primitive is associated with only one single data value or with *multivariate data*, which has to represent multiple data values (Aigner et al., 2011). Early energy monitors, mainly based on univariate data, show only single devices or the total consumption. In comparison, our survey shows that *multivariate data* approaches are increasing due to the disaggregation of consumption data. In most cases, tables and lists are used to visualize multivariate consumption data. Using charts and more advanced visualizations tend to be the exception.

Early monitors also show consumption as an abstract entity (Dillahunt et al., 2008). Our survey indicates a slight increase of systems that consider the consumer location (Castelli et al., 2014a; Jahn et al., 2010). Related to this increase, the number of time-based space and/or hierarchical approaches is also increasing. For instance, to aggregate consumers at room-level (Castelli et al., 2014a) or to subsume them under pre- and user-defined categories (Schwartz et al., 2013a).

5.4 Device Types / Output Medium

Besides the data sources, the *output medium* is another important factor that heavily influences design. Information design focusing on desktop PCs has a long tradition. However, our survey reveals that desktop PCs are not always the best

solution in terms of output medium. Feedback can often be more effective in various locations on different devices. Four main mediums are described in literature.

5.4.1 Ambient Artifacts

Ambient artifacts are artifacts that have been specially designed to provide feedback. A variety of forms and styles have been studied, e.g. Broms et al. (Broms et al., 2010) used a clock-based design artifact that was integrated in everyday life since they were already accustomed to looking at a clock. The Monster study (Kirman et al., 2010) is another example of layering known artifacts. Making use of the metaphor of the evil monster, the authors motivate users to act sustainably so that the monster is not annoyed. Another popular output medium is colored light, realizing ambient feedback in an abstract fashion (Maan et al., 2010; Pierce et al., 2008). Here, the color typically indicates actual or cumulative consumption.

5.4.2 External Displays

External displays can be installed on a wall or can be freely placed within the home. They show less but are tailored and typically easy to use (Sundramoorthy et al., 2010). Most often, they are located in the kitchen or living room, as generally a lot of energy is consumed in these rooms (Makonin et al., 2012; Rodgers and Bartram, 2011; Yun, 2009). It is important to take account of movement patterns, so that the display is located where the user can see it. On the other hand, conspicuous places might also stress users because, when they see the display, they may feel under pressure to save energy (Broms et al., 2010). Displays located directly on the electricity meter are technically preferred but are often not easily accessible for users (Pereira et al., 2012). The same holds for sockets, as displays might disappear behind furniture (Heller and Borchers, 2011).

5.4.3 Mobile Devices

Often mobile devices such as tablets and smartphones are used. Here, feedback design must consider the common guidelines of mobile and responsive design concerning screen size, interaction modality and context support (Gong and Tarasewich, 2004).

Regarding appropriation, mobile Feedback is used more often but usage duration is shorter and savings are higher (T. Liu et al., 2013). Further, Yun (Yun, 2009) reports that mobile feedback is primarily used in the discovery phase by consumers walking around and checking. After this phase, the mobile device was partially used as a stationary display as well (Yun, 2009). In addition, smartphones seem preferable to tablets (Kjeldskov et al., 2012). This preference is also because smartphones are more ready-to-hand. For instance, Kjeldskov et al.

(Kjeldskov et al., 2012) observed that users look at them in idle times e.g. when waiting for a bus.

5.4.4 Desktop PC

For complex tasks, PCs have some advantages due to screen size and computer power. This medium is mainly preferred by highly motivated users who use their computer on a daily basis (Grevet et al., 2010) and who want more and detailed information on their consumption (Castelli et al., 2017; Sundramoorthy et al., 2010). For this group, there are few access barriers (T. Liu et al., 2013), especially if feedback is provided by widgets that fit in with daily computer use (Kim et al., 2010b; Yu and Bhatti, 2014). However, PCs as an output medium are not recommended for less motivated and non-regular computer users.

5.5 Visual Forms

The last step within our taxonomy is to consider the various visual forms used in the literature. The quality of information design is based mainly on the appropriate mapping of data sources to visualize forms, taking into account the design objectives and the user's context, preferences and capabilities (Aigner et al., 2011; Card et al., 1999). This section provides an overview of the visualization techniques commonly used in feedback design to motivate and inform the user.

5.5.1 Bar-Graphs/Charts

Bar charts are the elements most used to visualize consumption. Most often they are used to give historical feedback (Gamberini et al., 2011; Grevet et al., 2010; Nuno Jardim Nunes, 2011; Parker et al., 2006; Petkov et al., 2011a; Strengers, 2011; Weiss et al., 2011, 2009). Some studies add extra information to the bar graph, such as color bar graphs displaying low, medium and high consumption (Kunold et al., 2011) or average consumption (Jain et al., 2012; Kjeldskov et al., 2012). Bar graphs are also used for the representation of non-time-oriented data, e.g. comparing the consumption of devices (Sundramoorthy et al., 2010), per person (Guo et al., 2013) or to other households (Crowley et al., 2011). In addition, vertical bar charts are sometime used for ranking (Odom et al., 2008; Petersen et al., 2009).

5.5.2 Line-Graphs/Charts

Line charts are another popular way to visualize consumption. Plain line charts are mostly used for displaying historical data (Foster et al., 2011; Jain et al., 2012; Jarrah Nezhad et al., 2014; Kjeldskov et al., 2012; Miller and Buys, 2010; Quintal et al., 2010; Weiss et al., 2009). In some cases, they are extended by comparison values e.g. from other households or averages (Dick et al., 2012; T. Liu et al.,

2013; Sundramoorthy et al., 2010; van Dam et al., 2010). Line charts are also used for real-time feedback (Kaliappan et al., 2012; Selvefors et al., 2013). In a few cases, we also found special line charts, e.g. using area charts for historical value (Heller et al., 2013; Selvefors et al., 2013) or area stacked line charts for non-time-oriented data, to show the relation of total savings between multiple areas (Grevet et al., 2010).

5.5.3 Gauge Charts

Gauge graphs are well known from dashboards e.g. in cars to show current speed. In feedback design, they are mainly used in a similar fashion to show current consumption (Foster et al., 2010; Frejus and Martini, 2015; Kunold et al., 2011; Weiss et al., 2011, 2009). Gauges can also be enriched by additional information, particularly to support comparison. For instance, to show whether historical consumption is lower, the same as or higher than present consumption (Kjeldskov et al., 2012).

5.5.4 Spider/Spiral/Clock Charts

Time has the singular property of being a linear flow but is simultaneously also cyclic (day, week, etc.). As a result, temporal data such as energy consumption has cyclic patterns (Aigner et al., 2011). One common way to visualize patterns such as these is to use clock/spider/spiral charts (Aigner et al., 2011). In our survey, we discovered some studies that adopted this strategy (Broms et al., 2010; Kunold et al., 2011; Nisi et al., 2013). In three cases, the hours were colored to represent low or high consumption (Nisi et al., 2013) or varying tariffs (Kunold et al., 2011; Prost et al., 2015).

5.5.5 Pie Charts

In our survey, pie charts were seldom used. Only two studies used pie charts, either to show the division between devices (Gamberini et al., 2011) or to show the consumption of different household members over a fixed period of time (Guo et al., 2013).

5.5.6 Textual/Numerical Elements/Tables

Textual elements were often used as an additional element to complement other visualizations. Numbers are mainly used in simple displays to show the exact value of current consumption (Banerjee, 2013; Costanza et al., 2012; Gamberini et al., 2011; Parker et al., 2006; Petkov et al., 2011a; van Dam et al., 2010; Yun et al., n.d.) or to show historical consumption (Foster et al., 2010; Petkov et al., 2011a; Yun et al., n.d.). Sometimes numbers are also used quantitatively to compare consumption with other households or one's own average (Foster et al., 2010; Petkov et al., 2011a). Two studies used text in the manner of story-telling (Q. Liu et al., 2013; Petkov et al., 2012). Tables are mostly

used to represent ranking in a social comparison challenge setting (Petkov et al., 2012, 2011b). Timetables are a special table form, which e.g. Kunold et al. (Kunold et al., 2011) use to balance planned energy-related actions in order to support load-shifting and forecasting.

5.5.7 Symbols

Visualizations are often enriched by symbols to increase the emotionality and interpretability of feedback. For instance, emoticons are popular symbols used to report a good, normal or negative consumption level, partly by social comparison (Foster et al., 2010; Kjeldskov et al., 2012; van Dam et al., 2010). Others use colors (Kjeldskov et al., 2012; Petersen et al., 2009) or arrows (Petkov et al., 2012) to indicate performance in terms of current or historical consumption. Costanza et al. (Costanza et al., 2012) use icons to tag input sources and show them in a time graph as additional contextual information. Symbols can further be used as units; for example, real-consumption appears only in the form of points (Heller et al., 2013) or leaves (Petkov et al., 2011a).

5.5.8 Landscapes and Abstract Forms

Landscapes and abstract forms are usually used for ambient visualization strategies. Manifold landscape schemes have emerged, ranging from ice-bears (Dillahunt et al., 2008); highlands with green grass and cows (Nisi et al., 2013); an underwater coral reef with fishes (Kim et al., 2010b); trees (Saunders et al., 2014) etc. However, the main principle remains the same: A beautiful, healthy, clean environment disappears or turns ugly when too much energy is used. In addition to naturalistic forms, abstract forms are also popular as feedback (Makonin et al., 2012; Rodgers and Bartram, 2011). The primary goal is to achieve aesthetically pleasing visualizations, yet sometimes other objectives are also addressed, e.g. Crowley et al. (Crowley et al., 2011) used bubbles with different colors and rotating speed to depict current consumption to make it easy for users to rate it.

5.5.9 Others

We also uncovered other, specialized forms of visualizing consumption: Sundramoorthy et al. (Sundramoorthy et al., 2010) use a clinical thermometer metaphor to display the average and highest consumption compared to other households. Costanza et al. (Costanza et al., 2012) use boxes of each device, where the size depends on the energy needed for a specific action. One feature of this visualization is to support mental “what-if” scenarios: When deleting a box (“not using the device”), the users see the impact on the overall consumption. Castelli et al. (Castelli et al., 2014a) use alerts in the smartphone status-bar to inform the user about potential spenders when leaving a room. Paay et al. (Paay et

al., 2014) use boxes in a timeline to show the duration of the on- and off-status of a device.

6 Common Issues, Trends, Gaps

As mentioned above, design issues and evaluation methods are major structuring elements within sustainable HCI. In the following, we highlight and present common issues, trends and gaps based on our analyses.

6.1 Design Issues

Common issues: Table 1 shows that various hot spots exist in feedback-design research, where more research has been done than in other areas. In particular, a major hot spot is shown up by the monitoring strategy. Addressing the rational consumer (Strengers, 2011), the major design goal is to provide accurate and correct feedback. To attain this goal, common design elements such as bar graphs, line graphs and text/numbers can be used. Most designs are quite complex and tend to adhere to the slogan "the more, the better". The counterpoint is the minimalist design, which applies the golden rule "as much as necessary and as little as possible". In terms of the amount, however, minimalist design seems to be an exclusive concept.

Another hot spot is presented by persuasion strategies focusing on the social norms and man's instinct to play. Table 1 shows that comparison presents a popular persuasion strategy, supplemented by conditioning, gamification and goal-setting. Most studies use tables and lists to visualize how a user's consumption compares to that of others. This visualization often takes the form of

	Monitoring (total: 30)	Comparison (total: 11)	Minimal (total: 6)	Interactive (total: 6)	Context-Aware (total: 4)	Gamification (total: 3)	Conditioning (total: 2)	Goal / Limit (total: 2)	Ambient (total: 6)
Bar graph	14	5	1	1	2	1	0	1	0
Line graph	14	4	1	0	2	0	1	1	0
Text/Number	9	7	3	5	0	2	1	1	0
Symbols	4	5	2	0	0	1	0	0	1
Gauge	6	2	0	0	0	0	0	0	0
Abstract	1	1	2	0	0	4	2	0	5
Clock/Spiral	5	0	0	0	1	0	0	0	0
Pie chart	1	0	0	0	1	0	0	0	0
Other	2	1	0	1	0	0	1	0	0

Table 1. Heat Map bringing Design Strategies (total number = studies with strategy elements) and Visual Forms together (red = high amount of studies, green = no studies in this category)

a ranking list enriched by symbols such as badges, credits, etc. as well as numbers e.g. information on total or relative consumption. Social comparison is rarely

realized by charts, which are more popular for comparative time series visualization.

Ambient design constitutes the third hot spot. Addressing the peripheral perception and the emotions of human beings, the primary focus relates to aesthetics. In contrast, issues such as unambiguousness and accuracy are less important. In realization, these issues are manifested by the preference of expressive, naturalistic and abstract forms in design.

Trends: Advanced monitoring, supplemented by such technical trends as more sensors, computer power and wearables at home, describe one particular trend. One issue associated with this trend is preventing information overload (Jacucci et al., 2009). We identified two strategies to deal with this overload issue (somewhat analogue to the direct manipulation vs. interface agents distinction (Shneiderman and Maes, 1997)).

One camp focuses on intelligent agents to provide contextualized and intelligent feedback beyond simply visualizing raw data, for instance, using sensors for heating, presence, door- and window-status to detect intention-behavior gaps and to make users aware of actual wastage (e.g. switching devices off) (Castelli et al., 2014a) and to recommend practices that promote lower consumption (e.g. concerning heating). The transition to home-automation is blurred and the challenge is how to cleverly combine intelligent feedback, advice and automation (Loviscach, 2011).

The other camp allows users more control to enrich and tailor the feedback concerning local needs and personal preferences. For instance, tagging consumers (Costanza et al., 2012) so that they are easier to compare or to aggregate and can therefore enrich the interpretability (Schwartz et al., 2013a). In principle, interactive feedback could be applied to both minimalistic and complex design. However, the greatest potential seems to be to visualize complex issues and to support complex analytical tasks. Interactive feedback has the additional potential to bridge the gap between minimalist and complex visualizations according to the InfoVis mantra *overview first, zoom and filter, then details on demand* (Shneiderman, 1996).

Concerning output media, most designs are implemented as web-apps to provide information independently of individual platforms. Mobile devices including tablets and smartphones are becoming more popular as output media and may be extended in the future to include watches and glasses too. However, designs and usages differ among the devices, e.g. smartphones are used in idle moments (Kjeldskov et al., 2012), displays before bed time (van Dam et al., 2010) and so on. In this regard, guidelines and best practices would be useful to fit the design to the different mobile usage scenarios.

A further trend is the connected home and the use of home clouds. Related to this trend, security (Grevet et al., 2010; Sundramoorthy et al., 2010) and privacy (Foster et al., 2010) topics are emerging, e.g. privacy-preserving technologies for

smart metering (Sundramoorthy et al., 2010) or providing advanced access control mechanisms (Stevens and Wulf, 2009) to regulate social comparison information disclosure. Another issue is to improve accessibility in a broad sense. Complicated log-in procedures (Broms et al., 2010) present barriers, and deterrents such as long response time (Costanza et al., 2012) could lead to non-usage. However, accessibility in the traditional sense has mainly been neglected in feedback design so far.

Research gaps: If the information deficit model (Wilhite and Ling, 1995) is taken seriously, feedback design is largely a special case of information visualization. We were therefore surprised to uncover just one, weak, link between feedback-design and information-visualization research in general (Card et al., 1999), and to time-oriented visualization in particular (Aigner et al., 2011). This missing link could well be the reason why feedback design uses standard visual forms while more advanced forms, such as TreeMaps and RiverGraphs, are neglected –they are, after all, established approaches in other areas for dealing with hierarchical and time-oriented data sources (Aigner et al., 2011). The same holds for interactive visual analytics techniques such as brushing, filtering, focus and context (Shneiderman, 1996). Feedback design would benefit from adopting such techniques to improve interactive CF (Costanza et al., 2012; Gustafsson et al., 2009b), especially because new innovative design system concepts are the biggest group to have emerged in recent years in the field of CF research. This finding points to *visual eco-analytics* research that supports users in exploring and analyzing interesting consumption phenomena. Such approaches, for instance, offer support when making more long-term decisions, e.g. when replacing old devices or switching electricity tariffs (Schwartz et al., 2013b). In addition, such approaches are also suitable for the area of organizational eco-feedback where multiple stakeholders, manifold data sources and various organizational demands (Castelli et al., 2015) must be considered.

6.2 Evaluating Design

Common issues: Concerning design evaluations, Froehlich et al.’s remark (Froehlich et al., 2010) is still valid that HCI studies focus on short-term oriented laboratory studies or qualitative field studies. The studies tend to be informal in nature, seeking feedback on the designed artifact as users perceive it. In addition, 20% of the studies were work-in-progress without any evaluation at all.

Regarding the methodological approaches, the reported interest in motivational factors (T. Liu et al., 2013; Makonin et al., 2012; Rodgers and Bartram, 2011; Sundramoorthy et al., 2010; Yun, 2009) is not just rhetoric; quite the contrary, in fact. Artifacts are evaluated from this motivational stance, asking users e.g. if the design would motivate them to save energy or examining in short-term studies whether an energy-saving effect can be observed.

Trends: One major trend is to draw attention to the diversity of users by taking into account gender (Al Mahmud et al., 2008), age (Rodgers and Bartram, 2011), motivation type (Petkov et al., 2011a; Selvefors et al., 2013; Sundramoorthy et al., 2010), attitudes (Grevet et al., 2010), prior knowledge (Guo et al., 2013), saving experience (Costanza et al., 2012; Petkov et al., 2011a) and energy awareness (Kjeldskov et al., 2012; Yun, 2009). All these factors seem to affect both the effectiveness of feedback and user preferences. For instance, Mahmud et al. (Al Mahmud et al., 2008) report that male and female perceptions of CF differ. Petkov et al. (Petkov et al., 2011a) remark that users experienced in energy saving preferred kWh while inexperienced users prefer CO₂ or money as units. Makonin et al. (Makonin et al., 2012) observed that feedback effectiveness depends on the busy-ness of the users. Kirman et al. (Kirman et al., 2010) stress that persuasion design could benefit from adapting individual preferences.

A special focus is on *low-motivated* users. This user group uses feedback systems less frequently and usually for a shorter time period. Based on this observation, Grevet et al. (Grevet et al., 2010) argue that feedback should relate more strongly to common habits and technology such as using mobile phones in idle times, which also influence the design. For instance, Broms et al. (Broms et al., 2010) recommend providing *less information first*, to illustrate if everything is “normal”, but showing *detailed information on request*. Another promising approach is to *periodically or event-driven remind the user* (T. Liu et al., 2013). Pereira et al. (Pereira et al., 2012) also gathered positive experience with low-energy consumers. This group also tends to believe they cannot increase their savings much more.

Another recent topic is *trustful processing showing what is normal*. This processing refers to the recurrently reported observation that simply visualizing raw data is insufficient and that meaningful information is requested. A common way to do this is therefore to *process the data*, classifying consumption as high, low or normal. Evaluations have demonstrated that people find this type of classification helpful. However, some studies also report skeptical users who mistrust the construction of normality. This mistrust especially holds when systems become increasingly complicated or rely on external data either from unknown users or on the statistical data of the average person (Schwartz et al., 2013b). In addition, if the processing is not transparent, users experience difficulties in relating the feedback to their own life and developing a feeling for their own consumption behavior (Heller and Borchers, 2011; Schwartz et al., 2013a). This mismatch points to the tradeoff that, on the one hand, data processing is becoming increasingly important to minimize the information overload and to maximize the information value while, on the other hand, the control and the power of interpretation must remain under a user's control. However, future studies should evaluate in more detail the data-processing procedures employed by users when exploring and interpreting CF.

Research gaps: Usability, user satisfaction and user acceptance have represented for a long time the standard evaluation criteria in HCI. Insofar it is surprising that only 11% (Gamberini et al., 2011; Jacucci et al., 2009; Petersen et al., 2009; Selvfors et al., 2013; Sundramoorthy et al., 2010; Weiss et al., 2011) of reviewed studies take these issues explicitly into account. Others might consider them indirectly, arguing they are the precondition for successful persuasion. For example, Selvfors et al. (Selvfors et al., 2013) show user acceptance and usage barriers are partially related to users' initial motivation.

7 Conclusion

Our paper contributes to the fast-growing field of sustainable HCI by highlighting current trends and research gaps of the last five years based on a systematic literature review.

We developed a taxonomy that focuses on design and identifies hot spots using current design strategies, data sources and visual forms. In addition, a trend was visible towards multiple data, mobile output media and the use of interactive and contextualized feedback-design strategies.

As our findings show, CF design unconsciously adopts concepts from information visualization, but a systematic adoption of proven designs and analytical techniques is missing today. Therefore, we suggest addressing the new complexity of multivariate, hierarchical data by studying information visualization at home in general and visual eco-analytics in particular. This could be a promising research area in the future

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