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Product features: Upgraded Functionality or Sustainability Problem? An environmental assessment approach for additional product functions and its application in the case of fridge-freezers

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***Abstract*—Next to primary functions, energy-related products have an increasing number of additional functions. This affects the overall environmental footprint, but the question is how? A number of European policy strategies, initiatives and measures, such as the Green Deal, the Circular Economy Action Plan,the Ecodesign Directive and the EU Energy Labelling, aim to ensure that the environmental impact of the overall product is better determined, communicated and finally reduced. A core element of these efforts is the DIN EN 4555x series of standards. However, there is currently no comprehensive and systematic classification of the additional product functions or an approach to assess the associated positive and negative environmental impacts. Therefore, we present in this study an environmental assessment approach for additional product functions and illustrate its application in the case of fridge-freezers.**

A key element of the life-cycle-oriented methodology is an assessment matrix to categorize and evaluate the direct, indirect and systemic impacts of products' functions. Based on semi-quantitative assessments of experts, the matrix provides an indication of how the additional function affects the overall environmental product impact as well as specific product aspects such as durability or reparability. Based on the results experts can discuss and better understand how specific functions can influence various stages of the product life cycle and how intended systemic changes or rebound effects could occur. As part of the approach, a representative survey was conducted to analyze consumers' knowledge and information needs. Based on the results, recommendations for purchasing decisions and the consumer information were developed.

This paper presents the results from the assessment of the additional functions of fridge-freezers.

Furthermore, the paper highlights practical experiences made from applying the presented approach. Conclusions are drawn on the potential of the approach to develop a more comprehensive understanding of additional product functions supporting circular design strategies and sustainable purchasing decisions of consumers.

***Index Terms*—circular economy, energy-related products, circular design, repairability, durability**

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I. Introduction

All products have an inherent conflict of objectives: how much does the product enhance human well-being and how much does its environmental impact jeopardise human life on the planet? Efforts to strike this balance have been known for many years. From today's perspective, it may not seem so, but the debate that preceded the introduction of the energy efficiency label was conducted with a broader set of indicators [1]. Recycling-oriented product design [2], the comparison of material costs and the service provided by the product-service system can be found already in 1994 in the MIPS approach [3]–[7]. This was preceded by the report to the Club of Rome, The Limits to Growth, published in 1972 [8]. Since then, the evidence and temperature of human-made climate change has been increasing, while the chance of limiting it to 1.5 °C has been decreasing [9]. With the 2030 Agenda at UN level [10], the European Green Deal [11], the Circular Economy Action Plan [12] and the proposal to revise the Ecodesign Directive [13], a large number of activities can be recognised that contribute to SDG 12 (sustainable production and consumption). The Ecodesign and Energy Labeling Working Plan 2022-2024 [14] provides a roadmap for which appliance groups will be assessed with a broader set of environmental indicators in the

near future. The series of horizontal standards EN 4555x [15] provides concrete approaches to measure and regulate aspects of material efficiency. These include: Durability, reusability, reparability, reusability and upgradeability, recyclability and recoverability, proportion of reused components, proportion of recycled material, use of critical raw materials, provision of information on material efficiency aspects. As an example, for the product group of smartphones and tablets, a specific index with information on reparability based on the reparability standard EN 45554:2020 will be visible to consumers from 2025 [16].

While the range of indicators is increasing, it seems that the variety of functions in the energy-related products (ErP) to be regulated is also increasing. This impression is also reflected in the number of consumer devices that can connect to the internet using IoT technologies. There were 3.3 trillion devices worldwide in 2018, the number has risen to around 10 trillion by 2023 and is expected to almost double to 19.5 trillion by 2028 [17]. According to the International Electrotechnical Commission [18], connected white goods will account for almost half of all machine-to-machine connections. Furthermore, additional product functions are not limited to establishing a connection to the internet; they complement the basic function in a variety of ways.

With the aim of defining different energy demands of on-, stand-by and off-modes, there are three function definitions in the International Electrotechnical Vocabulary that outline the topic of additional functions quite clearly.

primary function = "function providing the intended purpose" [19]
secondary function = "function that enables, supplements or enhances a primary function" [20]
tertiary function = "function other than a primary or a secondary function" [21]

Based on this, a working definition of additional functions was drawn up for this work: Additional functions are the functions of a product that are not related to the intended function or that supplement or reinforce the primary function. In other words, they are functions that are not required to ensure the primary function (See figure 1). Once the awareness has been sharpened, there are many examples of additional functions in everyday life: Kettles with LED lighting, hobs with countdown, food processors with an integrated recipe database, automatic switch-off functions for espresso machines, dishwashers with WiFi connection, etc.

Some of these functions appear to be primarily technical gimmicks, gadgets for a target group obsessed by technology [22]. Other functions reduce the overall footprint of the product, such as automatic switch-off functions. A comprehensive and systematic classification of the additional product functions and an approach for assessing the associated positive and negative environmental impacts are still lacking. Therefore, this study presents an approach for the environmental assessment of additional functions in products and illustrates its application using the example of refrigerators and freezers.

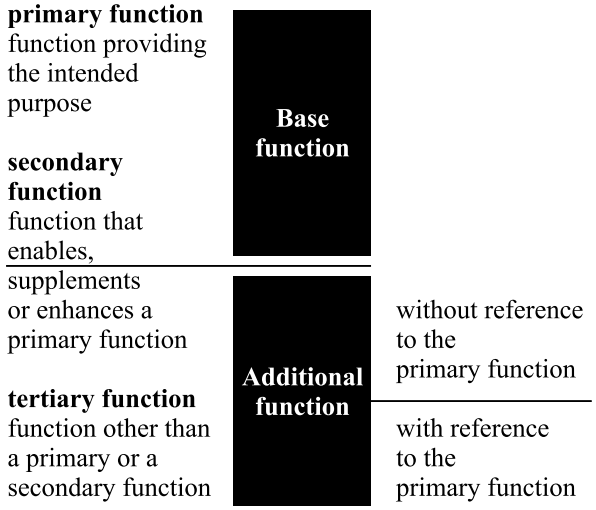

Fig. 1. Additional functions in relation to primary, secondary and tertiary functions.

II. Methods

The basic framework of the methodological structure consists of five successive working steps:

1) Identifying additional functions
2) Initial assessment by experts in evaluation matrix
3) Focus group dialogue
4) Survey on user perspectives
5) Information concepts for consumers

A. Identifying additional functions

In the first step, the additional functions are identified. For this purpose it is essential to define the product group itself. Refrigerating appliances are part of the Ecodesign and Energy Labelling Working Plan 2022-2024 [13] and legal minimum requirements are set by the Commission Regulation (EU) 2019/2019 [23] as well as an obligation to be labelled is defined by the Commission Delegated Regulation (EU) 2019/2016 [24]. With these two product-specific regulations, there are already definitions that outline what is meant by a refrigerating appliance. It is "an insulated cabinet with one or more compartments that are controlled at specific temperatures, cooled by natural or forced convection whereby the cooling is obtained by one or more energy consuming means;" [23]. The above-mentioned regulations also contain definitions of various additional functions. In addition to regulations, preparatory studies are also a good source of information for keeping an eye on product group-specific trends and technical developments. For example, the above-mentioned regulations were preceded by a preparatory/review study from 2016 [25]. Another source of information for identifying additional functions is the manufacturer's advertising. Screening the websites of manufacturers with a larger market share is particularly informative here to identify the latest

developments. The advertised functions can also be found frequently in product tests. These tests provide a good overview so that no relevant additional functions are overlooked in the multitude of device variants. It is often possible to determine the acceptance of the functions by the testers from such tests. For example, the consumer organisation 'Consumer Reports' aptly summarises the function of the 'Through-the-Door Ice and water Dispenser' as "This is one of the features most requested by buyers. Caveat: We find that models with this convenience also require the most repairs. Energy costs are higher, too, and you trade ice water for storage space." [26].

For refrigerating appliances, it was found that many differently labelled functions essentially fulfil the same purpose. Therefore, the additional functions identified need to be harmonised.

B. Initial assessment by experts in evaluation matrix

An evaluation matrix has been developed to assess the environmental impact of the identified additional functions. The matrix is designed in such a way that a number of experts can make a quick assessment for each additional function (See VI appendix). Applying the matrix enables to estimate the environmental impact of the additional function and to clearly categorise the functions. In addition to the already mentioned function categories of primary, secondary and tertiary, there is the category of appliance variations such as refrigerators, chest freezers, upright freezers and fridge-freezers[1].

Based on experiences from assessing environmental effects of ICT (Information and Communication Technology) [27], possible functions' impacts are divided into direct, indirect and systemic effects . These three categories are subdivided to enable more nuanced assessments. The direct environmental impacts are divided into product life cycle phases: Raw Materials and Manufacturing, Distribution and Packaging, Use, Maintenance and Repair and End of Life. The indirect environmental impacts and the systemic effects were subdivided according to a scheme for identifying and reducing rebounds [28]. In the section on indirect environmental impacts, impacts in the same area of need are queried, while in the section on systemic effects, impacts are asked that extend into another area of need. The indirect effects are subdivided into economic effects and socially mediated effects, e.g. psychological effects. In addition to the latter two subdivisions, the systemic effects also include the category "Technical effects". There are guiding questions in the individual columns of the original questionnaire to simplify to fill in the information. For example, the column 'technical effects' in 'systemic effects' had the text: "Are there technical effects on other devices or other fields of action? Examples: A chill compartment increases the shelf life of food and reduces food waste. Critical raw materials used for the touchscreen in the refrigerator door are no longer available for environmentally friendly technologies."

[1]The differences between the terms 'refrigerator' and 'fridge-freezer' are not important for this article and will be used synonymously as representatives of the product category 'refrigerating appliances'.

TABLE I
STRUCTURE FOR ASSESSING ENVIRONMENTAL EFFECTS OF ADDITIONAL PRODUCT FUNCTIONS WITHIN THE EXPERT CONSULTATION

Change in the analysed device and its life cycle							Change in other devices or in other fields of activity		
Direct environmental impacts (direct, technical/ material effects)					**Indirect environmental impacts (indirect effects due to monetary or social/psychological causes)**		**Systemic effects (change in effects of other devices or areas)**		
Raw materials and Production	Distribution and Packaging	Use	Maintenance and Repair	End of Life	Economically induced	Socially mediated	Technically conditioned	Economically induced	Socially mediated

The assessment is based on a 5-point scale:
-2 = Environmental impact worsens strongly;
-1 = environmental impact worsens;
0 = environmental impact remains similar;
+1 = environmental impact improves;
+2 = environmental impact improves strongly;
Supplemented by two possible statements that were only recorded in the qualitative evaluation
? = effect unclear;
+ - = environmental impact has both a positive and a negative effect.

C. Focus group dialogue

The focus group dialogue is integrated into the methodological process to record the users' views of the respective additional function and to be able to compare the users' assessments with the information from the evaluation matrix. It is of particular interest here whether there may be a fundamentally different view of certain additional functions. If, for example, a function with the tendency "environmental impact worsens strongly" emerged from the evaluation matrix and the participants in the focus group came to the conclusion that this function had very little influence on the environmental impact, this would indicate a need for research or probably a necessity to better inform users about this function.

The structure of the focus group dialogue follows the structure of the evaluation matrix. Divided into quantitative assessments by tally sheet and qualitative discussions. In favour of a brief presentation, the structure is only outlined concisely here. After a short introduction to the topic of additional functions, the participants were asked to provide information on the following questions for 6 selected functions with 2 votes each:

1) Which additional functions would you choose in a new fridge-freezer?
2) Which additional functions have the greatest positive environmental impact?
3) Which additional functions have the highest negative environmental impact?
4) Which of the additional functions has the greatest negative impact on your wallet?

D. Survey on user perspectives

The two previous methods are designed to identify details of environmental impacts and user behaviour in relation to additional functions. Even though they contain quantitative elements, they are fundamentally a qualitative approach. The survey focuses on a larger number of consumers and provides information about their usage behaviour and information needs. There was a general question section on the perception of additional functions of electrical appliances in the household. The participants were divided into specific product groups in the second part of the survey. Of these, 1019 entries were made for the group of refrigerators and freezers described in this paper. To avoid duplication, the questions asked in the online survey are presented directly with the analysis in the results section.

E. Information concepts for consumers

Based on the results of the previous steps, Consumer information can be developed to address identified information needs and preferences.

III. Results

A. Identifying additional functions

As a result of the first step, eleven additional functions are identified. These are the following:

1) Chill compartment
2) Auto-defrost
3) WLAN/ Smart refrigerator/ Control via app
4) Camera inside (in combination with WLAN)
5) Smart grid function
6) Fast freeze
7) Door alarm
8) Automatic door opening function
9) Door display with temperature indicator and control
10) Door display with calendar and communication tools
11) Ice cube maker (in the door) and water dispenser

The functions water dispenser, blast cabinet, fast freeze, chill compartment and auto-defrost can also be found in the according product Regulation (EU) 2019/2019 [21] and/or (EU) 2019/2016 [22]. Some uncertainties created here appear when looking at the terminology that manufacturers give to these functions. This becomes particularly clear with terms that describe either a colder unfrozen compartment or a chill compartment[2].

[2]Terms were found on the German-language websites of the manufacturers and have not been translated here.

Identified terms for unfrozen compartment:
hyperFresch (Plus); VitaFresh (Plus); DailyFresh; Cool Select+; Optimal Fresh+; (Ultra) Fresh Zone+; ExtraChill; UltraFresh; CrispZone; ZeroZone; EverFresh+; Frischeschublade; CrispZone; FreshZone; 0°C-Zone; FRESH-Balancer; Gemüseschublade

Identified terms for chill compartment:
hyperFresh premium; VitaFresh Pro; BioFresh-Safes (Professional): mit Meat & Dairy-Safe or Fruit & Vegetable-Safe; PerfectFresh Active; PerfectFresh (Pro); Cool Select+ (in Fach mit variabler Temperatur); Zero° BioZone; CoolRoom – 0°C-Zone; ChillerBox; Tieftemperaturfach

For some manufacturers, different terms were identified on different appliances that refer to the same compartment type according to the definition in the regulation. Thanks to the information on the product data sheet in accordance with (EU) 2019/2016, the compartments could be identified; without this information, it would be impossible to differentiate between them. This raises the question: What weight is given to the EU product data sheet when making purchasing decisions? It is possible that some consumers may have the intention of purchasing an appliance that contains a chill compartment, but make a different purchase decision due to the terminological diversity and its related uncertainty.

B. Initial assessment by experts in evaluation matrix

Eight experts have been contacted to assess the environmental effects of the identified additional functions. The experts have been identified based on a discussion with the project team and their professional network with specific focus on the expertise in the assessment of product related environmental effects and experiences on refrigerating appliances. As a result eight experts completed the assessment using the matrix. As a result, the summarised diagrams across all functions highlight a clearly negative picture for two functions (See figure 2, the individual function ratings can be found in the chapter VI appendix). The 'Door display with calendar and communication tools' was rated as having a negative environmental impact across all participants and categories. A similar picture emerges from the ratings for the 'Automatic door opening function'. The 'WLAN/ Smart refrigerator/ Control via app', 'Camera inside', 'Smart grid function', 'Fast freeze' and 'Ice cube maker and water dispenser' are rated negatively on average but with individual positive ratings in some categories. A look at the comments and the frequent '+-' information shows that the 'Smart grid function' and the 'Fast freeze' function at least have the potential to contribute to more than just a negative overall balance. The 'Door display with temperature indicator and control' function shows a slightly positive trend in the 'Socially mediated' category. The 'Chill compartment' and 'Auto-defrost' functions reflect the trade-off between these functions. Additional energy is used to keep food fresh for an extended period of time or to prevent the system icing up. Only the 'Door alarm' shows a fairly positive rating of the environmental impact.

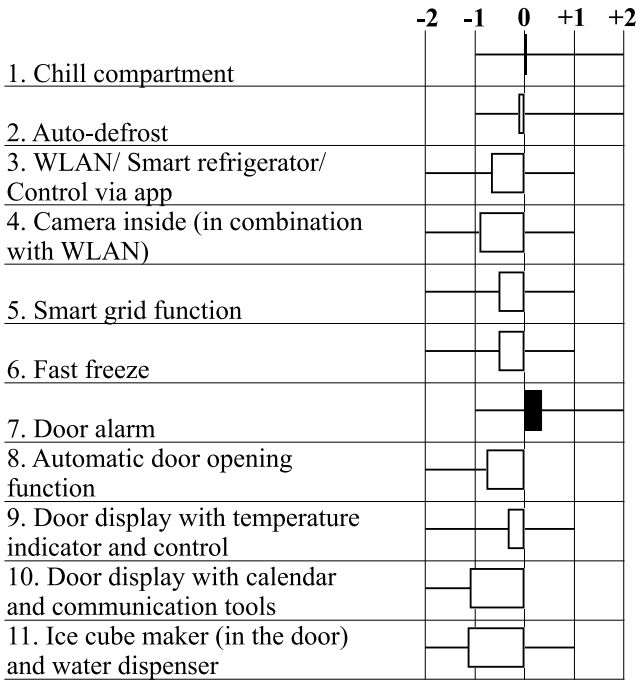

Fig. 2. Expert estimate of environmental impacts from additional function of refrigerating appliances, mean values from eight expert assessments

C. Focus group dialogue

Eight participants took part in the focus group dialogue, which took place as part of a summer school related to sustainability. The participants, largely students from different disciplines, proved to be well informed about sustainability issues during the discussion. To make the dialogue more focussed, six out of the 11 additional functions have been pre-selected based on the expert assessment. Hereby, the following logic has been applied: Two functions with the most positive expert assessment and two functions with the most negative assessment and one a neutral assessment have been selected (See figure 2). Additionally a more technical function (WLAN/ Smart refrigerator/ Control via app) has been included to inspire the discussion.

The discussion of questions which referred to the environmental impacts of the product functions brought up results largely similar to the expert assessments (See figure 3). For example, the participants associated the high negative impact with the 'Door display with calendar and communication tools' as well as 'WLAN/ Smart refrigerator/ Control via app'. The 'Ice cube maker' is rated by the participants more positively than the by in this assessment than in the previous one.

The discussion of the question which additional function would be chosen for a new fridge highlighted for two functions interesting perspectives: The 'Door alarm' receives the most votes for positive environmental effects, although the question on the preference shows that it is not overly popular in the group. 'Chill compartment' and 'Auto-defrost' are seen as positive, the negative effects of these two functions are lower compared to the results of the expert survey. In the following discussion, the key theses from the expert consultation were confirmed and supplemented with personal perspectives.

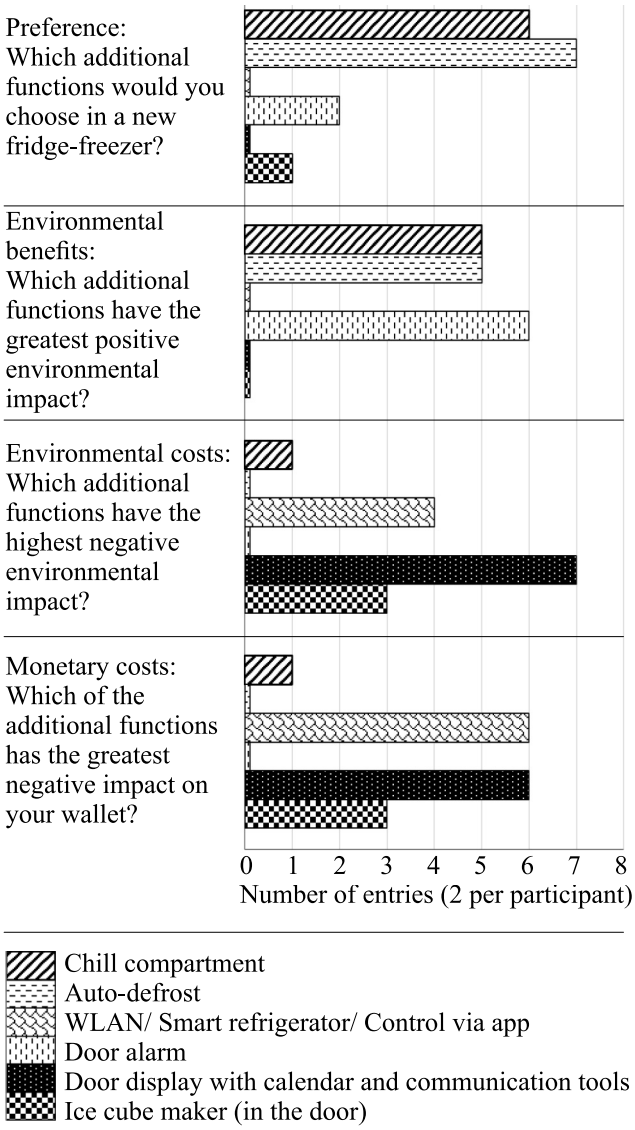

Fig. 3. Survey of eight participants on six specified additional functions of fridge-freezers

D. Survey on user perspectives

The research activities described so far provide a plausible estimate of how additional functions of refrigerating appliances affect the environment. A following question is whether the majority of consumers have similar views and preferences. Embedded in a larger survey, 1019 people were asked explicit questions about refrigerators in an online survey. The backgrounds of the respondents are outlined in Table 2. As the following answers did not show any significant differences when sorted by gender, age group, education and income, the

answers are summarised for the overall group. Gender, age groups, education and income distribution were representative for Germany in the survey conducted.

The first set of questions addresses the basic preferences of consumers (See figure 4). With the introducing sentence: ”Assuming that your domestic fridge is broken and you are going to buy a new one in the next few days, give your assessment of the following statements: When buying a domestic fridge, it is important to me that...” the interviewees positioned themselves on four preferences on a Likert scale.

1) ’... I get a solid appliance with the basic functions.’
   Here, 424 people fully agreed and 379 people tended to agree. The sum of the votes with ’strongly disagree’ and ’somewhat disagree’ amounts to 6 % with 63 responses.
2) ’... I have the latest technology.’
   Slightly fewer people agreed with this statement. Those in favour are clearly in the majority at around 67 %. However, this question does not specify whether these are so-called technological gadgets [29] or technology that increases energy efficiency.
3) ’...I purchase a durable product.’
   This statement clearly has the highest approval rating with almost 90 %.
4) ’...it looks high quality.’
   The lowest level of approval was given to the question about appearance. 43 % agree with this statement, whereby the number of respondents stating that a high-quality appearance is not or not very important is significantly lower at 21 %

It should be noted here that the attitude-behaviour gap [30] will probably result in different purchasing decisions than the responses in this survey.

The second set of questions remains in the area of user preferences and explicitly addresses the additional functions (See figure 5) Respondents were asked to put themselves in a situation in which they were about to buy a refrigeration appliance. They were asked to indicate which functions are important for the purchase decision. To increase the quality of the answers, the functions were briefly explained during the enquiry:

1) Chill compartment, in which the temperature is approx. 0 °C. Keeps some foods fresh for much longer
2) Auto-defrost, automates defrosting
3) WLAN/ Smart Refrigerator/ Control via app, cooling appliance can be controlled remotely
4) Camera inside (in combination with WLAN), take a look inside the cooling unit from anywhere
5) Fast freeze, function for rapid cooling and freezing
6) Door alarm, signal if the door is open for a long time
7) Automatic opening function, opening the door by sensor or voice command
8) Door display with calendar and communication tools, turns the refrigerator door into a multimedia device
9) Ice cube maker and water dispenser, offers ice cubes and cold water for instant access

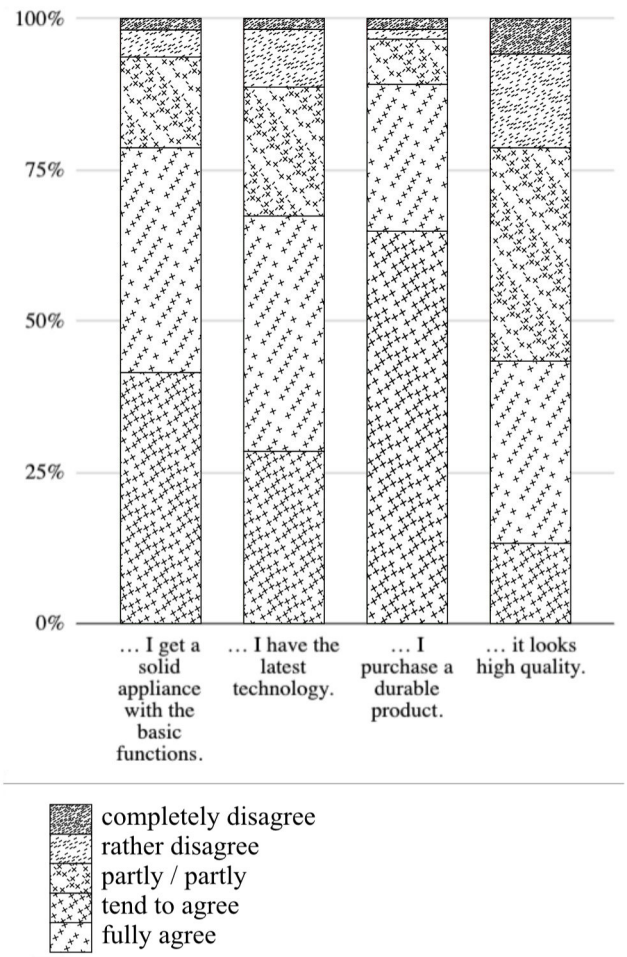

Fig. 4. Answers to the introductory question: ”Assuming that your domestic fridge is broken and you are going to buy a new one in the next few days, give your assessment of the following statements: When buying a domestic fridge, it is important to me that...”

The function with the highest priority is the ’Auto-defrost’ function with 64 %. This was rated as not important or rather not important by 11 % of respondents. The door alarm is the second most important function with 62 % of respondents. The fast freeze function was slightly more popular in this survey with 53 % approval than the chill compartment with 39 % cumulative approval. The remaining functions were not a high priority for the majority of respondents. The smart remote control of the refrigerator was the lowest priority. Across all responses, it can be seen that 47 % of the responses were ”rather not important or not important at all”, 20 % were ”partly / partially” and 30 % were ”very important or rather important”. This reluctance towards additional functions is also consistent with the responses from the first set of questions in this survey.

The third set of questions asks consumers to rate the previously mentioned additional functions in terms of their sustainability potential (See figure 6). As in the previous assessments, the door alarm emerged as the winner, with

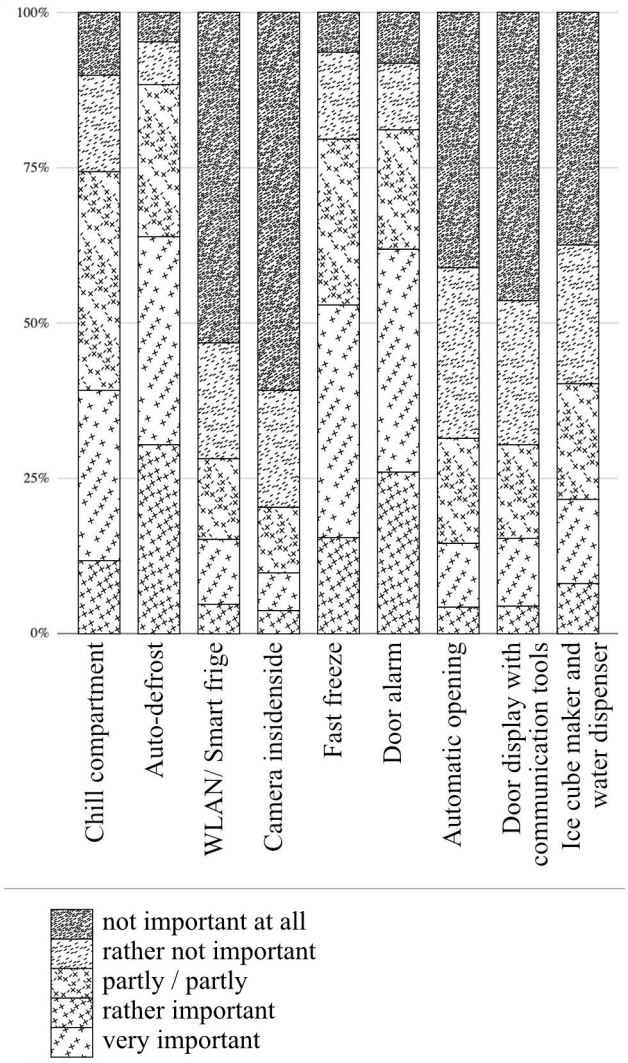

Fig. 5. Answers to the question: "Assuming your domestic fridge is broken and you are about to buy a new appliance, which of the following additional functions are important for your purchase decision?"

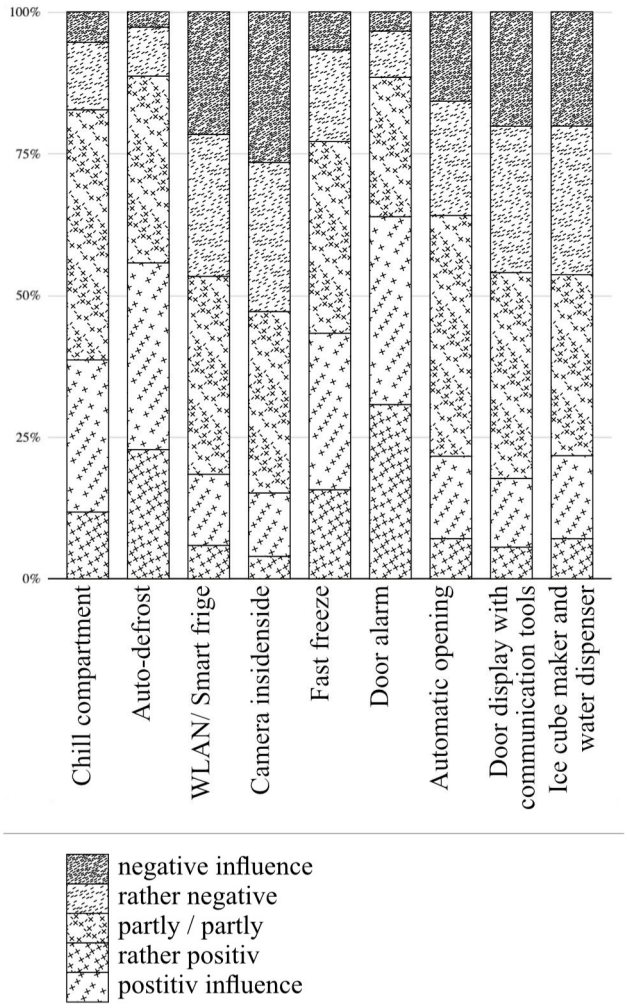

Fig. 6. Answers to the question: "Assume that your domestic fridge is faulty and you are about to buy a new appliance. Estimate how the following additional functions will affect the sustainability of the appliance."

64 % of responses suggesting a positive sustainability effect. Followed by Auto-defrost with 56 % positive votes. Fast freeze and chill compartment also still has a predominantly positive sustainability rating. For 'Camera inside', 'WLAN/ Smart refrigerator/ Control via app', 'Door display with calendar and communication tools', 'Ice cube maker and water dispenser' and 'Automatic door', the votes that see a negative influence on sustainability dominate. This continues the trend from the previous assessments, whereby a positive influence is stated much more frequently here. For the last five functions mentioned, a positive sustainability effect is assumed for almost 20 % of the responses.

E. Information concepts for consumers

This work has resulted in a flyer for consumers (See VI appendix). It is divided into three sections. In section one, questions are asked about users' preferences, which can be answered with 'yes' and 'no'. In section two, the answers result in a list with additional functions to help consumers find the product they are looking for: A product with only those additional functions which are desired, but no more. In section three, there is a very brief explanation of what the function does, including an assessment of what environmental impact it has, as well as a rating of whether this function is advisable from an environmental perspective.

IV. Discussion

A. Identifying additional functions

Even the first step provides insights and an impressive variety of functions, at least for people who do not work with this product group on a daily routine. In addition to the variety of functions, there was an even larger variety of terms for the cooling appliance. Some of these could be deciphered by comparing them with the EU data sheets. However, during the research it seemed almost impossible to determine whether the

terms chosen by the manufacturers were used synonymously with other functions or whether a slightly different function was hidden behind them. From the authors' point of view, there should be at least one systematic overview for consumers that simplifies classification across manufacturers.

In a longer term, it might also be worth considering making alternative suggestions to the product group. In other words, proposing a product-service category that offers the consumer a similar service, but in a different way. Just like brooms and hoovers are both bought to clean the floor. This link has not yet been systematically established.

B. Initial assessment by experts in evaluation matrix

The evaluation matrix has proven successful in the opinion of the authors. Compared to environmental life cycle assessments (LCAs) available for many products and their main functions, detailed and comprehensive assessments are unlikely to be conducted for the various additional functions of products. In this light, the semi-quantitative and expert-based approach is practical, a less time-consuming and systemic assessment. With the matrix, it is possible to quickly uncover undisputed findings and identify hotspots for deeper analyses and discussion. Particularly where the opinions of the experts differ, research should be carried out extensively. The assessments of several experts reduce the white "noise" [31] of a single assessment. However, the possibility of systematic errors in the assessments cannot be avoided. In general, it would be good to increase the number of experts involved. For the 'Chill compartment' and 'Auto-defrost' functions, the expert assessment highlighted that the environmental effect depends on the specific usage behaviour. However, a deeper literature analysis on the 'Auto-defrost' function helps to classify it as a recommendable function [32], [33]. Further research is needed on the 'Fast freeze' function. This function will not come close to the performance of a commercial blast freezer and for users who buy most of their food from the supermarket, using an insulated bag could be a more energy-efficient solution than the 'fast freeze' function.

C. Focus group dialogue

The focus group showed that the assessment from the experts and the views of informed consumers were largely consistent. This suggests that for none of the functions the participants have a fundamentally wrong understanding of the environmental effects. The format of the focus groups proved to be well suited to aligning a specialist discourse with the users' real world [34] and capturing structured usage scenarios.

D. Survey on user perspectives

The results of the survey show that consumers place large importance on a solid and, most importantly, durable product. In terms of preference for additional functions, those functions that are related to the primary function of the refrigerator and improve or enhance it, such as the 'chill compartment' or 'auto-defrost', are highly appreciated. Simple interventions that avoid unnecessary energy consumption appear also to be highly accepted.

The survey has also been shown that some functions probably have an overestimated environmental potential. 'WLAN', 'Camera', 'Automatic door', 'Ice cube maker and water dispenser' have a very clear negative influence in the views of the experts. In the user survey, these functions have a surprisingly good rating with around 20 % positive votes. On the one hand, there is a need for research into how these sustainability attributions arise. On the other hand, there seems to be a need to better inform consumers about the environmental impact of such functions and their potential to reduce the product's durability or energy efficiency.

E. Information concepts for consumers

The flyer for consumers (See VI appendix) is a potential way to summarise the results from applying the methodology for consumers. Whether the flyer has an impact on the consumers purchasing decisions in favour of products with less environmental impacts has not been addressed in this study. This could be the focus of future research. In general, the topic of additional functions should be included in other and more sophisticated information offerings so that consumers can make informed purchasing decisions more easily. On the one hand, to be able to consciously decide against functions that have a negative environmental impact. On the other hand, to know which functions have an additional benefit and when, even outside of advertising promises. The methodology of the flyer could be transferred to digital formats for this purpose. Information on additional product functions and their environmental effects could for example be integrated in the digital product passports, a key measure in the proposed European Ecodesign Directive.

V. Conclusion

This paper has identified a large number of additional functions for fridge-freezers and provided an approach for their environmental assessment. We have presented a methodology that makes it possible to estimate the environmental impact of these functions from an expert's perspective and compare them with the consumer's view points. For the fridge-freezer product group, it has been shown that the estimates from the experts' view, the focus group discussions and the consumer survey are quite aligned. This indicates that the consumers are generally quite informed about environmental effects of additional functions for fridge-freezers.

Depending on the context of use, the 'chill compartment' has the potential to generate a positive environmental impact. The 'Auto-defrost' function will lead to increased energy savings for the majority of consumers. Only those who have a very good routine in defrosting the freezer compartment could save energy without this function. The functions 'WLAN/ Smart refrigerator/ Control via app', the 'Smart grid function' and the 'Camera inside' are not particularly highly rated in the consumer surveys and, according to the assessments, tend to have a negative impact on the overall environmental balance

of the refrigerator. In the future, a positive effect could emerge here if refrigerating appliances interact more with power grids and sustainable routines through these functions, but this is more a long-term perspective that will not yet play a role in the purchase of the next refrigeration appliance. The authors see a need for further research into the 'fast freeze' function. This was very in-line with the survey respondents, but is estimated to have a negative environmental impact. In the survey, the 'door alarm' was highly accepted and has the potential to have a positive impact on the environmental footprint of the fridge-freezer through a simple mechanism. From the authors' point of view, a debate on whether this function should be included in each new refrigerator could be useful. The 'Automatic door opening function' can be a great relief for people with handicaps, otherwise it probably produces a less durable and more resource-intensive appliance. The 'Door display with temperature indicator and control' has no major impact. The more timeless look, and therefore possibly the more durable appliance, is given to consumers with a control inside. The 'Door display with calendar and communication tools' does not appear in the survey to be particularly important. As the associated technology is subject to completely different innovation cycles, this function is clearly not recommended. The 'Ice cube maker and Water dispenser' have a negative environmental impact according to the experts. Only consumers who see a large benefit from this function should choose it. For example, if users use ice cubes very frequently and this function significantly increases their well-being in everyday life. This paper identified the need for research into functions with ambiguous environmental impacts. Initial solutions were identified to inform consumers about additional functions. These activities should be continued to inform a broader target group about the opportunities and risks of additional functions. In addition, the activities should be adapted for other product groups, as there are likely to be many other devices with additional environmentally relevant functions that have not yet been adequately identified.

The study confirmed that additional functions can impact the environment and have the potential to help increase energy efficiency. However, some functions could overload the devices and make them more vulnerable to repairs or reduce the durability of the product. Circular design processes should therefore carefully consider additional functions in energy-related products to contribute to the goal of a sustainable circular economy. In order to support better purchasing decisions, manufacturers should place more emphasis on using clearly understandable and consistent language in product information. On the consumer side, it is wise to think carefully about one's own needs before making a purchase decision.

REFERENCES

[1] S. Wölfel, *Weiße Ware zwischen Ökologie und Ökonomie: umweltfreundliche Produktentwicklung für den Haushalt in der Bundesrepublik Deutschland und der DDR*. No. 70 in Hochschulschriften zur Nachhaltigkeit, München: oekom, 2016.

[2] W. Jorden, "Recyclinggerechte produktgestaltung als grundlage fur ein optimales stoffrecycling," *Resources and Conservation*, vol. 14, pp. 119–131, Mar. 1987.

[3] F. Schmidt-Bleek, *Wieviel Umwelt braucht der Mensch?: MIPS — Das Maß für ökologisches Wirtschaften*. Basel: Birkhäuser, 1994.

[4] F. Schmidt-Bleek and U. Tischner, "Produktentwicklung : Nutzen gestalten - Natur schonen," tech. rep., Wirtschaftskammer Österreich, Wien, 1995.

[5] F. Schmidt-Bleek, U. Tischner, and T. Merten, eds., *Öko-Intelligentes Produzieren und Konsumieren*. Berlin: Birkhäuser, edición: 1997 ed., Mar. 1997.

[6] F. Schmidt-Bleek, Stefan Bringezu, Fridrich Hinterberger, Christa Liedtke, Joachim Spangenberg, Hartmut Stiller, and Maria Jolanta Welfens, eds., *MAIA: Einführung in die Material-Intensitäts-Analyse nach dem MIPS-Konzept*. Wuppertal Texte, Berlin, Basel, Boston: Birkhäuser, 1998.

[7] C. Liedtke, K. Bienge, K. Wiesen, J. Teubler, K. Greiff, M. Lettenmeir, and H. Rohn, "Resource Use in the Production and Consumption System—The MIPS Approach.," *Resources*, vol. 3, no. 3, pp. 544–574, 2014.

[8] D. H. Meadows and Club of Rome, eds., *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. New York: Universe Books, 1972.

[9] "IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.," tech. rep., Intergovernmental Panel on Climate Change (IPCC), July 2023.

[10] United Nations, "Transforming our world: The 2030 Agenda for Sustainable Development," Oct. 2015.

[11] European Commission, "The European Green Deal," Tech. Rep. COM/2019/640 final, European Commission, Dec. 2019.

[12] European Commission, "A new Circular Economy Action Plan For a cleaner and more competitive Europe," Tech. Rep. COM(2020) 98 final, European Commission, 2020.

[13] European Commission, "Proposal to establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive," Mar. 2022.

[14] European Commission, "Ecodesign and Energy Labelling Working Plan 2022-2024." https://energy.ec.europa.eu/publications/ecodesign-and-energy-labelling-working-plan-2022-2024_en.

[15] DIN, "General methods for the assessment of the ability to repair, reuse and upgrade energy-related products; German version EN 45554:2020," Oct. 2020.

[16] K. Schischke, J. Rückschloss, M.-C. Schlegel, J. Zöllinger, N. F. Nissen, and M. Schneider-Ramelow, "The European Union's Energy Label for Smartphones: Does it Guide Consumers to Make Environmentally Sustainable Choices?," in *2023 IEEE 13th International Conference on Consumer Electronics - Berlin (ICCE-Berlin)*, (Berlin, Germany), pp. 1–6, IEEE, Sept. 2023.

[17] Statista, "Consumer IoT: market data & analysis," tech. rep., Statista, Sept. 2023.

[18] M.-C. Schlegel, C. Koch, M. Mirtsch, and A. Harrer, "Smart Products Enable Smart Regulations—Optimal Durability Requirements Facilitated by the IoT," *Sustainability*, vol. 13, p. 4395, Apr. 2021.

[19] International Electrotechnical Commission, "IEC 60050 - International Electrotechnical Vocabulary - Details for IEV number 904-03-02: 'primary function'," Nov. 2014.

[20] International Electrotechnical Commission, "IEC 60050 - International Electrotechnical Vocabulary - Details for IEV number 904-03-03: 'secondary function'," Nov. 2014.

[21] International Electrotechnical Commission, "IEC 60050 - International Electrotechnical Vocabulary - Details for IEV number 904-03-04: 'tertiary function'," Nov. 2014.

[22] Y. Strengers, "Smart energy in everyday life: Are you designing for resource man?," *Interactions*, vol. 21, pp. 24–31, July 2014.

[23] European Commission, "Commission Regulation (EU) 2019/2019 – ecodesign requirements for refrigerating appliances," Oct. 2019.

[24] European Commission, "Commission Delegated Regulation (EU) 2019/2016 – energy labelling of refrigerating appliances," Mar. 2019.

[25] R. Kemna, "Preparatory/review study Commission Regulation (EC) No. 643/2009 with regard to ecodesign requirements for household refrigeration appliances and Commission Delegated Regulation (EU) No. 1060/2010 with regard to energy labelling of household refrigeration," final Report, VHK, ARMINES, Viegand & Maagøe, Wuppertal Institute, 2016.

[26] "Refrigerator Buying Guide." https://www.consumerreports.org/appliances/refrigerators/buying-guide/, Oct. 2023.

[27] L. M. Hilty and B. Aebischer, "ICT for Sustainability - An Emerging Research Field," in *ICT Innovations for Sustainability* (L. M. Hilty and B. Aebischer, eds.), vol. 310, pp. 3–36, Cham: Springer International Publishing, 2015.

[28] J. Buhl, L. Echternacht, and J. von Geibler, "Rebound-Effekte : Ursachen, Gegenmaßnahmen und Implikationen für die Living Lab-Forschung ; Arbeitspapier im Arbeitspaket 1 (AP 1.2a) im INNOLAB Projekt "Living Labs in der Green Economy: realweltliche Innovationsräume für Nutzerintegration und Nachhaltigkeit"," 2015.

[29] E. Morozov, *To Save Everything, Click Here the Folly of Technological Solutionism*. New York: PublicAffairs, first edition ed., 2013.

[30] A. Kollmuss and J. Agyeman, "Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior?," *Environmental Education Research*, vol. 8, pp. 239–260, Aug. 2002.

[31] D. Kahneman, O. Sibony, and C. R. Sunstein, *Noise: A Flaw in Human Judgment*. New York, NY Boston London: Little, Brown Spark, first little, brown spark paperback edition ed., 2022.

[32] M. Amer and C.-C. Wang, "Review of defrosting methods," *Renewable and Sustainable Energy Reviews*, vol. 73, pp. 53–74, June 2017.

[33] P. Bansal, D. Fothergill, and R. Fernandes, "Thermal analysis of the defrost cycle in a domestic freezer," *International Journal of Refrigeration*, vol. 33, pp. 589–599, May 2010.

[34] C. Liedtke, C. Baedeker, M. Hasselkuß, H. Rohn, and V. Grinewitschus, "User-integrated innovation in Sustainable LivingLabs: An experimental infrastructure for researching and developing sustainable product service systems," *Journal of Cleaner Production*, vol. 97, pp. 106–116, June 2015.

VI. Appendix

1) Screenshot of the evaluation matrix's input screen (see figure 7)
2) Evaluation of the expert matrix for the different additional functions (see figure 8 and 9)
3) Flyer for consumers with information on additional functions in the refrigeration appliances (see last page)

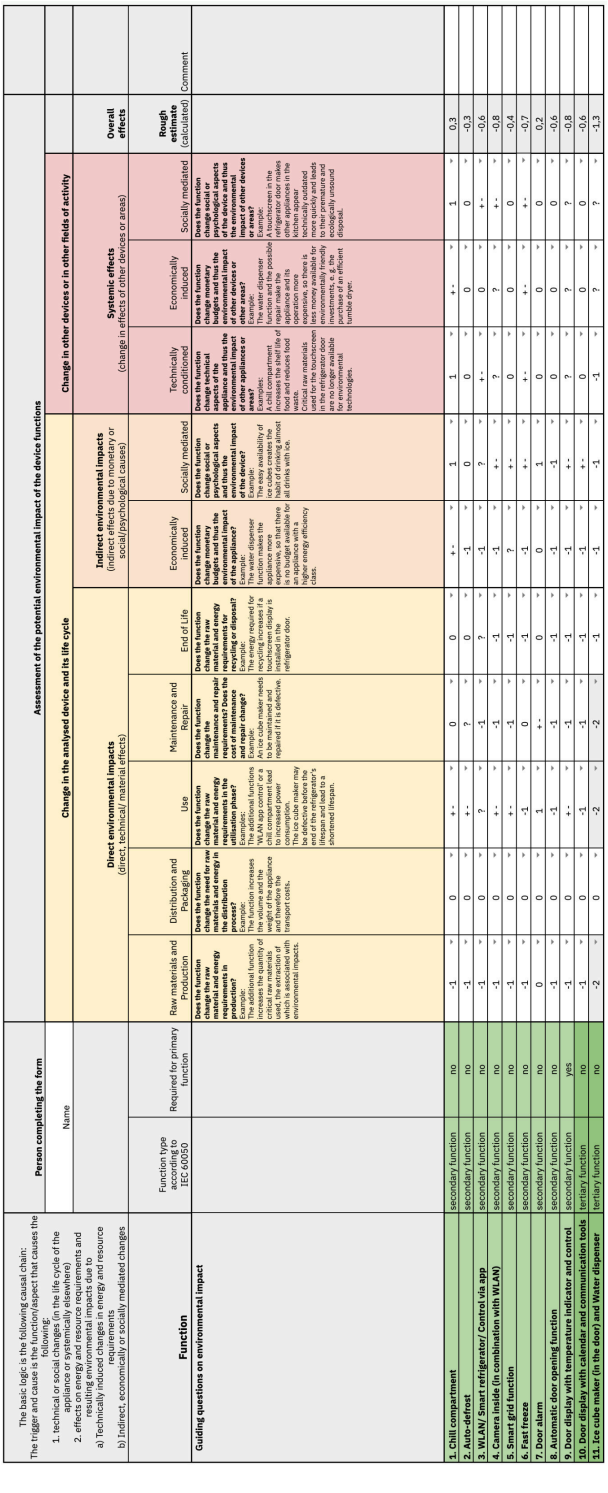

Fig. 7. Screenshot of the evaluation matrix's input screen

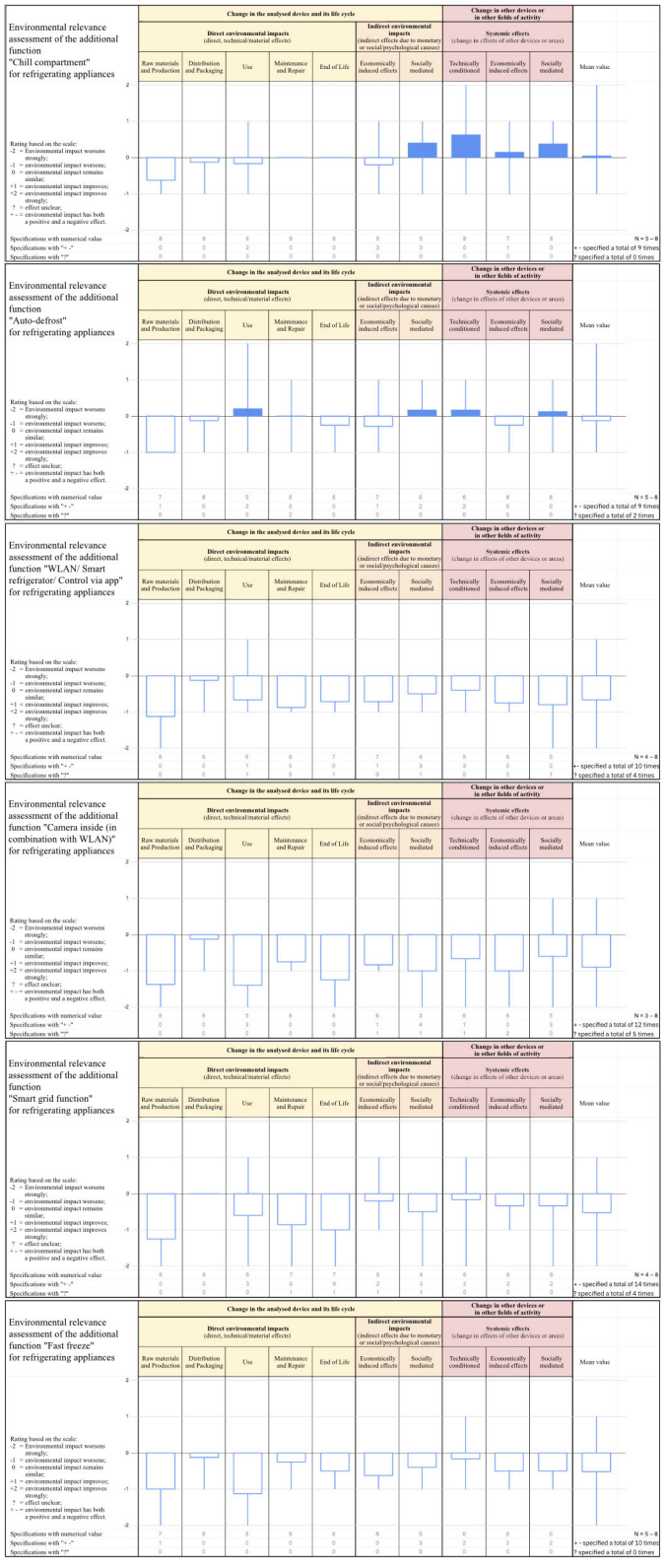

Fig. 8. Evaluation of the expert matrix for the additional functions 1–6

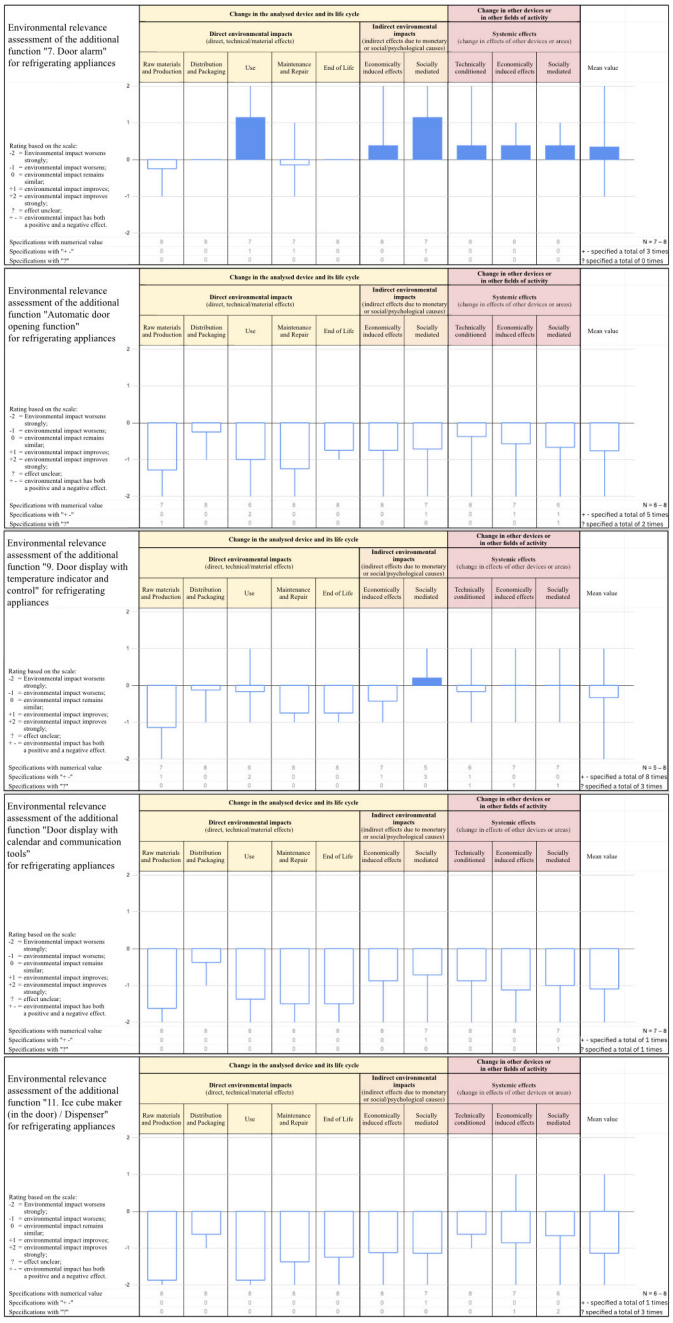

Fig. 9. Evaluation of the expert matrix for the additional functions, 7-11

TEST YOUR DEMAND FOR ADDITIONAL FUNCTIONS IN REFRIGERATING APPLIANCES

1. Please tick the appropriate box.

From time to time, food spoils in my fridge, because I change my plans and don't consume the food and then don't use it up quickly enough.	☐ Yes ☐ No
My freezer compartment is frequently iced up and it takes a while to defrost it.	☐ Yes ☐ No
I'm a big Internet of Things (IOT) fan and need full control over my refrigerating appliance, even when I'm far away from it.	☐ Yes ☐ No
I keep buying far too much food, because I have absolutely no idea what's left in the fridge at home.	☐ Yes ☐ No
In my home, several devices already react to peaks in the power grid, i.e. to short-term high d emands for power.	☐ Yes ☐ No
I frequently freeze large quantities of home-harvested and/or cooked food.	☐ Yes ☐ No
It has already happened that I forgot to close the fridge or the door didn't close properly because something was in the way.	☐ Yes ☐ No
Opening a refrigerator door manually restricts my ability to act.	☐ Yes ☐ No
The temperature inside my fridge and the option to check it even when it is closed is important to me.	☐ Yes ☐ No
Screen time, we all still need more screen time.	☐ Yes ☐ No
Ice cubes should be in almost every drink.	☐ Yes ☐ No
Actively cooled tap water should be available within a fingertip's reach.	☐ Yes ☐ No

2. Unfold the sheet..

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YOUR LIST OF ADDITIONAL FUNCTIONS

3. It seems that these are the additional functions for your ideal refrigerating appliances.

RATINGS FOR ADDITIONAL FUNCTIONS FROM AN ENVIRONMENTAL PERSPECTIVE

	4. Here is an evaluative description for classification	***Evaluation***
Chill compartment	Compartment in which the temperature is approx. 0 °C. Requires more energy than other cooling compartments, keeps some foods fresh significantly longer.	+
Auto-defrost	Automates defrosting, which consumes energy. A refrigerator with an iced-up freezer compartment consumes more energy than a refrigerator without a layer of ice.	+
WLAN/ Smart refrigerator/ Control via app	Cooling unit can be controlled remotely. Requires additional resources for functions that are easily dispensable.	-
Camera inside (in combination with WLAN)	Access the cooling unit from anywhere at a glance. Requires additional resources, does not display the contents as well as a human view inside the refrigeration appliance.	-
Smart grid function	Reacts to utilisation peaks in the electricity grid. Not yet enough infrastructure available to realise environmental benefits.	-
Fast freeze	Reacts to utilisation peaks in the electricity grid. Not yet enough infrastructure available to realise environmental benefits.	-
Door alarm	Signal when the door has been left open. Simple mechanism to protect food, electricity bills and the climate.	++
Automatic door opening function	Opening the door by sensor or voice command. Requires additional resources and increases the possibility of a fault.	--
Door display with temperature indicator and control	Allows the appliance settings to be read from outside. Controls inside are often more resource-efficient and less susceptible to damage.	-
Door display with calendar and communication tools	Turns the refrigerator door into a multimedia appliance. As cooling appliances and multimedia appliances have different innovation cycles, your cooling appliance will presumably look outdated after a short time, despite the high level of resource input.	--
Ice cube maker (in the door)	It offers convenient ice cubes at the price of higher resource, cleaning and recycling costs.	--
Water dispenser	Provides cold water from the refrigerator door at the cost of more resources, cleaning and recycling effort compared to a bottle of water in the refrigerator.	--

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