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Statement of Originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation, or both.

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1. INTRODUCTION

In 2021, the European Commission increased the target of greenhouse gas emission reduction to at least 55% below 1990s levels by 2030. To reach the ambitious climate goals, citizens need to play a much more active role in transforming the energy sector. The EU-funded AURORA project aims to empower several thousand citizens across five locations in Denmark, England, Portugal, Slovenia, and Spain to make more informed energy decisions. By crowdfunding local energy communities and installing ca. 1 megawatt in photovoltaic (PV) power, citizens will become active ‘prosumers’, transforming the energy system at large and democratising its governance. Moreover, they will monitor their individual energy behaviour in a mobile app, and receive automated recommendations in return.

One of the objectives of the project is to create the first generation of Near-Zero Emissions Citizens. To achieve this, we develop a Near-Zero Emissions Citizen Label, which citizens can use to understand the emissions linked to their energy-related behaviour, including electricity, heating/cooling and mobility. The aim of such a label is to raise awareness among citizens about the carbon emissions related to their energy-related behaviour. Together with other strategies and incentives that will be implemented in the mobile app, the label acts as a tool to encourage citizens to reduce their energy consumption and carbon emissions. Since AURORA plans to engage citizens in crowdfunding of the community-owned PV systems, the label will also take into consideration of the electricity production from the crowdfunded PV, or other renewable sources that the citizens already own.

This report covers the technical approach and methodology to set up the Near-Zero Emissions Citizens Label. A fundamental part of the technical framework is the definition of the citizen CO_2 emission labelling, which is also described in detail. The report is structured as follows. Section 2 covers the definition of the labelling system. First, subsection 2.1 includes a review of experiences in which labelling has been used as a strategy for behaviour change. Second, subsections 2.2 reviews the currently available carbon footprint calculators and the main sectors covered by them. Here we explain the rationale why we choose to develop the Near-Zero Emissions Citizens labels with a new set of calculations. Subsections 2.3 describes a proposal for the labelling scheme to be used in the AURORA project. Section 3 deals with the estimation of the citizen carbon emission that are linked to energy behaviour. The calculation methodology behind the proposed citizen carbon emissions label to be implemented in AURORA is presented and described in detail. This carbon emission labelling will first be implemented in an excel sheet and later as part of the app developed in the project.

We would like to stress that the objective is not to develop yet another full-fledged carbon footprint calculator, many of which are already available in different languages and used in different countries. Instead, the intention is for the labelling system to work as a “personal trainer”, which citizens can quickly refer to and understand what the emissions related to their energy behaviour imply, as compared to the European Green Deal target. This labelling system will become the backbone of the future AURORA mobile app, where citizens provide relevant data on their energy consumption, understand the emissions associated with it, and receive customized suggestions on how to reduce it. Through this, we hope to raise new energy awareness among citizens and drive behavioural changes through a combination of strategies.

Due to the reasons mentioned above, currently only the following three sectors are included in the citizen carbon emission labelling in AURORA: household electricity, heating, and transport. The rationale for focusing on these sectors is simple: these sectors are closely related to energy

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consumption, and the carbon emission is less complicated to estimate than others, such as food. This makes the labelling more straightforward to citizens while directing their attention to energy-related behaviours specifically. In addition, it is easier to drive behavioural changes in these sectors, such as opting for public transport over private cars and switching the domestic consumption to renewable energy sources, etc.

However, it is worth mentioning that future projects could be dedicated to further expanding the labelling system, adding more sectors (e.g. food and drink consumption) to the calculation.

2. LABELLING SYSTEM

2.1 Labelling as a tool to drive behaviour change

As behavioural changes of consumers play an indispensable role in the European energy transition, the AURORA project aims to empower civil society to adopt a leading role in the energy cycle through innovative long-term citizen engagement with energy sustainable behaviours. Key drivers to encourage and foster sustainable consumer behaviour have been studied and reported in the literature, and they cover behaviour changes in multiple aspects: from energy saving to food and drink choice, to travel. In particular, White et al. reviewed the available literature on these key drivers and proposed a framework with the acronym SHIFT, indicating the importance of harnessing one of the following: Social influence, Habit formation, Individual self, Feelings and cognition, and Tangibility, to encourage more sustainable consumer behaviours [1]. The SHIFT framework provides an thorough overview of the different drivers that can be exploited to encourage behavioural changes. Using this framework, we are able to quickly identify drivers and strategies that we can use in the AURORA project. White et al. point out that no single strategy in the framework works "best", and combing strategies can be impactful, depending on the context of specific behaviour and the intended target [1]. This is useful when we design the tools in AURORA: as we try to design something that prompts people to change their energy behaviour, multiple drivers mentioned in this framework should be taken into consideration. A summary of the key drivers described in the framework can be seen below (Figure 1).

Social influence	Habit formation	Individual self	Feelings and cognition	Tangibility
• Social norms • Social identities • Social desirability	• Discontinuity to change bad habits. • Penalties • Implementation intentions • Making it easy • Prompts • Incentives • Feedback	• The self-concept • Self-consistency • Self interest • Self efficacy • Individual differences	• Negative emotions • Positive emotions • Information and learning • Eco-labelling • Framing	• Matching temporal focus • Communicate local and proximal impacts • Concrete communications • Encourage the desire for intangibles

Figure 1 Summary of key drivers of sustainable consumer behaviour change: SHIFT framework by White et al.

When AURORA proposed creating a Near-Zero Emissions Citizens identity label, the concept was borrowed from existing energy efficiency and carbon emission labels for products such as house appliances and vehicles, which is believed to be familiar to European consumers. According to the Carbon Trust, over two-thirds of the consumers surveyed in different countries in Europe and the USA think carbon labelling is a good idea [2]. In the literature, environmental sustainability labels,

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in general, positively affect the selection and purchase of more environmentally sustainable food and drink products [3]. On the other hand, the label we would like to create in AURORA applies to citizens, therefore we need to be particularly cautious about it. The following section focuses more on identity labelling and how it affects behaviour towards sustainability.

For a behaviour change to be more bottom-up and permanent, the Changing Energy Behaviour Guidelines recommend a change-oriented approach where people are mainly intrinsically motivated and enabled to change with the help of external reinforcing factors such as feedback from peers and experts [4]. It is therefore important to investigate some personal level and social level drivers for behavioural change. Referencing to the SHIFT framework, we identify two main aspects: social identity and self-identity, and try to understand from the literature how we can harness these when designing the labelling system in AURORA. Therefore, the review below tries to understand pro-environmental behaviour through certain selected perspectives, which we deem relevant to the design of a labelling system in AURORA, but it is in no way an attempt to summarize all strategies for energy behavioural change. Following what is commonly used in the literature, pro-environmental behaviour entails not only energy or water saving but also environmentally friendly behaviour such as recycling or purchasing fair trade products.

One facet of social influence examined by White et al. is social identity [1]. It describes the ways that people internalize identity-defining attributes based on their membership to a social group [5], for example, a region, a neighbourhood or, as a student at a particular university. Many have argued that individuals' pro-environmental behaviour is influenced or even motivated by the values and identities of the group to which they see themselves as a member [6] [7]. It is thus not difficult to deduce that one's social identity could impact one's energy behaviour, as energy problems could affect a group. Bollinger and Gillingham gave an example where households in California are more likely to adopt PV panels if the neighbours (ingroup) have done so [8]. In their summary of previous studies, Klöckner suggested that a feeling of belonging to a larger social group (e.g. a municipality, a country, or the EU) might strengthen the feeling of being obliged to contribute to energy saving [9]. In the context of AURORA, the theory of social identity and examples of how social identity could affect energy behaviour support our initial proposal of transforming existing communities into energy communities. Since there is likely already an association of membership with existing communities (i.e. universities or councils), identifying the existing communities as "pro-energy transition" adds one more attribute to the group, which would likely be internalized by the members. In other words, what we propose here is to extend the social identity from "we are members of a group" to "we are members of a pro-energy transition group". In addition to the idea of belonging to a certain local community, AURORA will also emphasize that equivalent energy communities are being stablished at other EU universities and regions. This aims at reinforcing the idea of belonging to the EU and participating in the European energy transition.

Values and identities at both personal- and group-level influence climate actions [6] [10]. Indeed, factors associated with the individual self can have a powerful influence on their intentions, preferences, and behaviour. Van der Werff et al. studied the concept of environmental self-identity in relation to energy behaviours [11]. They defined environmental self-identity as "the extent to which you see yourself as a type of person who acts environmentally friendly". Accordingly, people with stronger environmental self-identity are generally more likely to act pro-environmentally [11]. Their findings suggest pro-environment self-identity is positively linked to energy behaviour, such as choice of renewable energy and energy saving at home [11]. Other studies in Europe [12] [13] further confirmed that pro-environmental self-identity could account for substantial variation in energy saving attitudes and consequently energy saving behaviour. Linking this to AURORA, we

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need to be aware that the tool we are going to propose should aim to enhance environmental self-identity.

Whether the technique of identity labelling could enhance environmental self-identity is the next question that we try to find answers to. Some researchers observed one's environmental self-identity can be strengthened by past pro-environmental behaviour which in turn promotes subsequent pro-environmental behaviour, indicating positive spill-over [14]. On the other hand, others observed that in certain circumstances past pro-environmental behaviour could lead to negative spill-over (i.e., decrease in future pro-environmental behaviour), because people feel less obliged to carry out other pro-environmental behaviour, or use past behaviour as an excuse to avoid other more difficult pro-environmental behaviour [15]. Due to the inconsistency mentioned here, Lacasse conducted a labelling treatment to examine if receiving an "environmentalist" label based on past pro-environmental behaviour could alter the spill-over [16]. Her result suggested reminding individuals of their past pro-environmental behaviour with an environmentalist label is an effective way to strengthen the environmental self-identity and increase the positive spill-over effect [16]. Eby et al. also argue that social identity labels can drive behaviour in the direction of that label and approaches that use shame and guilt (i.e., being labelled as "non-green" consumers) could be counterproductive and lead to a reduction of the possibility of subsequent pro-environmental behaviour [17]. This is important to the design of the labels in AURORA and we must take into consideration in designing the labels: they should try to avoid shaming those who have higher emissions or consumptions.

Although Schwartz et al believe that green identity labelling (e.g. "green shoppers" or customers "who care for the environment") alone shows a significant positive effect to encourage pro-environmental purchases of products such as more energy efficient light bulbs and house appliances [18], another study seems to suggest that such identity labelling is most effective when it is supported with behavioural evidence [19]. Understandably, people may be less likely to accept a label arbitrarily allocated to them, so labelling alone without reference to past behaviour may be ineffective [16]. However, in Schwartz's study, consumers who receive emails with headlines "for those who care for the environment" do not necessarily demonstrate previous pro-environmental purchases, nonetheless the technique increased the sales of the advertised white goods, as compared to a control group who received emails with headlines "the best products for your home". We did not find further solid evidence in the literature comparing the acceptance level of an identity label between those who receive a green identity label without reference to past behaviour and those who receive a green identity label with reference to past behaviour. Reflecting on these findings and being aware that designing a social science experiment to address this question would be out of the scope of the project, we aim to design a labelling system in AURORA that is meaningful for and relevant to the citizens, by taking into consideration their past energy behaviour.

Based on these studies, we conclude the technique of identity labelling could be an effective tool in driving behaviour change, especially when it could harness the impacts of both social and personal identity. In addition, we are aware that to be successful in driving behaviour change the labelling system's implementation and dissemination need to be combined with other strategies. One crucial point to note is that the identity label should be designed to be meaningful and relevant by taking into consideration citizens' energy behaviour, which in turn is affected by a multitude of factors, such as, where people live, what infrastructure is available, etc.

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We then explored what makes a label design more effective, and most articles study a product label rather than an identity label. Although they are not the same, some suggestions proposed in the literature are included here and worth considering in AURORA. In an EU policy brief, Dessart et al. argue that a graded label approach is more effective in product eco-labelling, as opposed to positive label and negative label, to promote more sustainable purchase decisions [20]. AURORA's rationale is to encourage citizens to make behavioural changes and gradually move from one level to another and eventually achieve "Near-Zero Emissions Citizen". A stepped approach could provide information of various levels and act as feedback to citizens to potentially stimulate further behaviour change, until a "Near-Zero Emissions" level is achieved. In addition, a graded label could potentially harness the impact of other drivers mentioned in the SHIFT framework [1] to drive behavioural change, for example, through means such as goal-setting and harnessing the effect of self-efficacy, which can be made possible through the future AURORA app.

Other findings regarding effective product eco-label design includes combing carbon footprint information with traffic light colour ranking [21], and appealing to the specific context (e.g., cultural and social background) [22]. In the study Thørgersen conducted, the traffic light technique was applied to ground coffee to amplify the effect on consumer choice of coffee [21]. There are already other real-life examples of this technique, for example, the EU Energy label. In AURORA, we could see the benefit of applying a colour scheme, as it makes the label more intuitive when citizens are used to associating green as "go" and red as "no-go". The choice of the final label's names, levels and colours was discussed within the consortium (see 2.3.2). As will be further illustrated in the sections below, each demonstrator country has a different carbon footprint baseline for an average citizen, due to several reasons such as the country's existing energy mix, and climate zone differences, we need to take into consideration these specific contexts to make the labelling relevant and robust.

As already noted, multiple drivers and strategies should be taken into consideration in AURORA to drive behavioural changes. The dissemination and implementation of the Near-Zero Emissions Citizens is carried out in the future AURORA app. One of the goals of the mobile app is to encourage and help citizens form new habits and change behaviour in the long run. To achieve the goal, the Near-Zero Emission Citizens labelling will be coupled with a series of other strategies in the mobile app. Examples include but are not limited to social norms, incentives, competition, nudges, etc; they work on different psychological and/or social drivers. As the scope of this document focuses on the description of the Near-Zero Emissions Citizens Label, other strategies will not be elaborated on in detail here.

We are aware that applying labels to individuals might raise potential questions of ethical concerns. If misused, it could be problematic in a dystopian world. Another work package in AURORA deals specifically with the topic on ethics (Work Package 7). During the consortium meeting in Evora in May 2022, we discussed that the labelling should be completely voluntary and confidential, and it should never be used to classify or rank citizens. It is important to point out that labels do not intend to categorize or rank citizens' personal quality; instead they are one tool to reflect our carbon emissions associated with their household electricity, heating and transport. People are encouraged to use the labels to explore their own carbon emission level and how they can reduce emissions through simple changes in behaviour.

One way to mitigate the potential problems caused by an unlikely misuse of this citizen carbon emission labelling is include disclaimers in the mobile app. Another way is to implement different settings in the future mobile app. While some citizens choose to be "public" users and are open to

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campaigns such as competition, some may prefer to be more “private” and want to find out their own energy consumption and carbon emissions just for own information. The app should allow users to change their settings and freely opt-in or out of the different campaigns.

2.2 Review of currently available calculators

The labelling system in AURORA is linked to carbon emissions. To evaluate whether we should simply link labels to results from existing carbon calculators, or devise another calculation for the Near-Zero Emission Citizens labels, we conducted a review of currently available carbon footprint calculators.

A number of standardized carbon footprint protocols have been developed over the past decade. The GHG Protocol[1], for example, establishes comprehensive global standardized frameworks to measure and manage greenhouse gas (GHG) emissions from private and public sector operations, value chains, and mitigation actions. However, it’s recognized that the GHG Protocol standards were not developed to be an accounting standard for individuals and that all principles might not be applicable to lifestyle calculations. Therefore, currently, there is not a universally accepted method for personal or household carbon footprint calculation.

In the absence of such a standard, several non-profits, academics, and companies have sought to develop robust methodologies for measuring and managing personal carbon footprints. Some of these calculators- such as the World Wildlife Fund calculator (UK), UC Berkeley Cool Climate Calculator (US), and the Klima app (from Climate Labs GmbH, Germany) - are based on user inputs and questionnaires addressing their food, energy, transport, and purchasing behaviours. Others - such as the Ducky app (joint project with the Norwegian University of Science and Technology) and the Svalna app [23] (from Svalna AB, Sweden) - have developed methodologies that blend top-down approaches with bottom-up approaches. Finally, other entities such as the developers of the Aerial app (from Corso Technologies, Inc., US) are investigating ways to leverage non-financial data sources, such as transportation data, to construct carbon footprints [24].

Several authors have highlighted that there are no standards regarding how carbon footprint calculators (CFC) should be programmed, nor the methods or calculations they should incorporate to get consistent results. This implies that very different values can be estimated from similar user behaviors, or even with the same inputs, which reduces the credibility of CFC to promote actual changes. On the other hand, it is common that calculators are not accompanied by sufficient information to contextualize the results (or this information is not properly communicated), which does not facilitate users’ understanding of the results or the ways to reduce their carbon footprint. In addition, CFCs measure the actual emissions derived from the user’s consumption, but they are less suitable to provide quantitative information on alternative choices, beyond general guidance to reduce personal emissions. In other words, they inform about the impact of the actual behavior (that is after the consumption was made), but they fail to inform about different alternatives before the consumer decision is taken [25]. Also, calculating the carbon footprint of an industry, product, or service is a complex task. The industry, for example, uses Life-Cycle Assessment (LCA) to analyze a product's entire life cycle in terms of sustainability, where carbon footprint may be one of many factors taken into consideration. However, LCA analyses require a great deal of detailed

[1] Greenhouse Gas Protocol (GHG Protocol) was jointly convened in 1998 by World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI).

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data, which could be costly, both in terms of time and labor. Also, there is a certain degree of subjectivity involved in LCA since it requires the analyst to draw a "system" boundary around the process that they are researching. This system boundary may differ across studies, leading to a lack of comparability across different LCAs of the same process. An authors review of 167 LCA studies on electricity generation and the resulting emissions find that often different LCA methods are used and/or system boundaries are not chosen equally, which challenges the comparability of the derived results [26] [27]. Although online carbon calculators have not been the subject of extensive scholarly studies, a few prior studies have tried reviewing the results, methodologies, and effects of online carbon calculators. Padgett et al. [28] compared the output of 10 different US carbon calculators using the same input and concluded that the results vary by several metric tons per person despite the calculators using seemingly similar calculation approaches. Murray & Dey [29] studied 11 websites offering individuals and businesses to become "carbon neutral" based on online calculation tools. They concluded that all 11 calculators requested input assumptions in different formats and that the estimated greenhouse gas emissions ranged from 6 to 11 tons per capita between the different calculators. Kenny & Gray [30] conducted a similar study but focused on the output from 6 different international calculators based on Irish input data. It was concluded that results varied by as much as 5 tons per capita per year. Therefore, it is evident that users are likely to get very different results depending on which calculator they choose. Other problems pointed out in studies reviewing online carbon calculators include poor documentation, not considering all carbon sources such as food and purchases, not adjusting for international trade flows, and not adjusting for income or consumption as well as the number of people living in a household. All this means that a clear majority of calculators appear to systematically yield underestimated carbon footprints [31]. The results of a study by Weber et al. [32] found that the calculation of carbon footprints for products is often riddled with large uncertainties, particularly related to the use of electronic goods. Weber found that a cache of variables, from production and shipping to technology used in creating a product, can alter the accuracy of carbon footprint labeling.

We conducted a review of 24 online calculators (refer to Appendix A) to assess the common practices used in the calculation of carbon footprint for individuals. To make sure the final sample is a good representative of the currently available calculators, the following steps were taken: first, a list of over 50 calculators was assembled by using the most comprehensive journal publications ([31] [33] [34]) on the subject of carbon footprint calculators. Second, a google search was conducted to make sure all top 20 results for a web-based calculator are included, and also to add a few newly developed mobile applications that were mentioned in news articles and recommended by environmental websites. Third, an initial review of each calculator's webpage was conducted to eliminate the ones that were simply a copy or a link from another calculator, the ones that were no longer available online, and also the calculators that were specific to other areas than individual footprint such as carbon footprint of food or air travel. These steps led to a list of 22 calculators, to which two more calculators – the SITRA lifestyle test (from the Finnish Innovation Fund Sitra) and IMPACT Community carbon calculator (UK) - were also added based on the recommendations of other members from the AURORA project. The most used categories in carbon footprint apps and programs include:

- Home Energy: Most available calculators take household energy usage into account, but not all of them adjust for house size and only use country/state average data.
- Transportation: Many calculators consider all forms of transport such as cars, public transport, and air travel. However, reviewers have stated that the data for these calculations is rather

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generic. For example, no calculator considers the type or age of a car or uses accurate measurements for air travel based on the plane's type of fuel and average overall weight. Some new mobile applications also use GPS data to calculate carbon emissions from transportation.

- Food and other goods: Many modern calculators include an estimation of food carbon footprint based on the diet type. Some calculators also include carbon footprint for various goods. These calculations are mostly made by LCA and the top-bottom approach.
- Water and Waste: Fewer calculators consider these two categories.

The share of each category for the 24 online carbon footprint calculators is shown in Figure 3, demonstrating that household energy, transportation, and food are the most common categories considered by calculators.

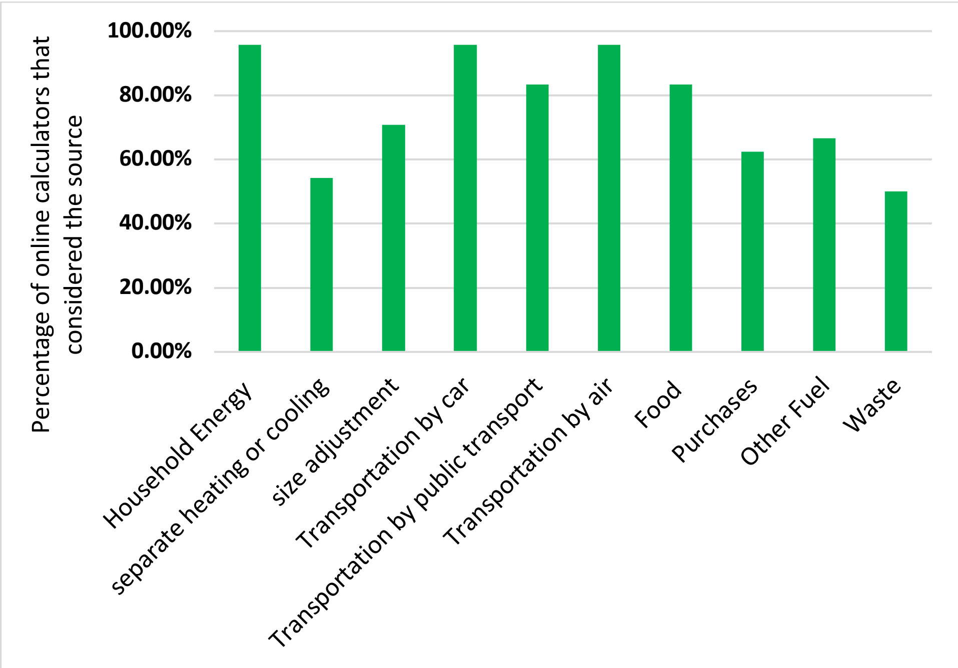

Figure 2 Sources considered for calculation of carbon footprint by 24 online CFCs

Most of the applications available today are fairly new and need much more development to be effective in the long-term. It is common to see two main deficiencies in most calculators. Firstly, nearly one third of calculators reviewed are country-specific and use a single-country database, meaning their data cannot be useful to anyone outside of that country. Second, not all calculators provide an in-depth methodology report. In the 24 calculators (refer to 'Available Data', Appendix 1), 45% include a report that mention their data sources, 33% present their methods in a short report without much detailed explanation, and only 16% provide access to their databases. Additionally, three calculators offer API access to their program, but only one calculator, NGC (Nos Gestes Climat), is open access so users could access everything within the program. However, like many other calculators, the NGC calculator is designed for a single country's residents, meaning the database is only specific to that one country, and all available scripts are written in the native language.

Accordingly, we are unable to find a single carbon calculator that meet all the transparency, inclusivity, and accuracy requirements we set for our own calculator development. Thus, the need to develop a new program could not be eliminated by using an existing one. Although developing a new set of calculations, even one with simpler functions such as our own, is still a long and

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demanding task, it does bring certain advantages. Now we will be able to alter and enhance features according to feedback and the needs of the project, and we will know for certain that our results are not affected by any other assumptions except the ones made and reported here. Specific examples of options we hope to include are, for example, users will be able to see their emissions if they were living somewhere else. Only with a new set of calculation that utilizes comparable data from the same database, this becomes meaningful. In addition, we will be able to incorporate aspects of solar communities built during the project into the calculation. Finally, the future AURORA app being open-source means that in addition to being transparent to all users, there is a way to keep the application going after the end of the project's lifetime so that people could also benefit from it in the future.

Although the calculation methods could be improved, carbon calculators offer a wide variety of interesting activities and solutions for people to both reduce and offset their carbon emissions. The CitiCAP App, for example, rewards residents of Lahti, Finland for greener transport choices. In practice, personal carbon trading allows people to benefit from reducing their carbon emissions. Each user receives a weekly carbon budget. If they do not consume their budget, by using sustainable travel choices, such as taking the bus or cycling, they earn credits for what they have not used. These can be exchanged via the app for discounts on consumer services, products, or city services [35]. From the 24 reviewed calculators, 42% offered options for investing in or donating to offset projects.

Having reviewed these calculators, one of the main questions coming to mind is 'how effective are they in reducing emissions?'. It is therefore important to stress that research in this field is still ongoing and evidence about the user experience of calculators and their effects on behaviour is currently limited and inconclusive. A Study by Kok and Barendregt [36] show that calculator users can be divided into two groups with different motivations and needs: Explorers and Environmentalists. For both user groups, calculators increase awareness. In some cases, this results in behaviour change. While some studies show positive results, most of the interventions entail more than just filling out a calculator and receiving emissions and tips. They include focus groups, personalised reduction scenarios, persuasive techniques, or Carbon Rationing Action Groups. In addition, one of the biggest challenges of CFCs is getting people to come back to the calculator frequently and reconfigure their daily practices to reach a sustainable level of footprint. It has been suggested that goal setting and continuous feedback can help engage users in the long term. But even though research has shown that frequent feedback can help people change behaviour, e.g., reduce energy use, the extent of behavioural change can vary greatly [23] [37] [38]. Also, easy-to-take actions can be problematic due to the risk of focusing on incremental changes and efficiency rather than questioning and reconfiguring the unsustainable practice [33].

This concrete lack of evidence regarding the outcomes of carbon footprint calculators is important to us, but it should be noted that the project's main aim is not to study the full psychological and social effects of the developed calculator, but to simply use it as a motivating tool and assess the general results in combination with the outcome from the solar PVs crowdfunding in order to push citizens towards near-zero emission targets.

Some final points about carbon footprint calculators based on the conducted review:

- Based on the number of questions in the 24 reviewed calculators, it seems that applications and calculators with long and detailed questions are unfortunately not very popular. It might

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be better to have simple questions first to draw in users, and then have an extra part for more detailed questions for interested users.

- Nowadays, most CFCs try to come up with ways to increase positive impact by proposing social comparisons, environmental advice, and carbon offsetting methods. This approach also comes from the fact that people might avoid uncomfortable information in a variety of realms. In essence, people may avoid information that they suspect will challenge their beliefs or make them feel bad about their choices in some way [39]. On the other hand, It has been suggested that eco-guilt from being confronted with a comparison of their footprint to their peers, could lead people to partial support for a pro-environmental group [40]. Naturally, the downside to such comparison, if one's footprint is smaller than average, could lead to what is argued to be misplaced contentment [36].
- As suggested by Auger et al. [39], It might be beneficial for the program to encourage people to start small and then move towards bigger lifestyle changes. These changes, even small, could have a ripple effect through society. When someone installs solar panels on their roof, their neighbours are more likely to install the panels too, a trend that's shown in multiple studies [8] [41] [42]. Empirical work has shown that goal-setting increases people's focus and motivation, especially if they are about to miss their goal. Goal-setting has also been shown to affect people's persistence in carrying through with certain changes [23]. Several environmental psychologists have emphasized the need of guiding pro-environmental behaviour against those actions that have a greater environmental impact, particularly when they do not require continuous efforts [25].
- Integrating these programs with popular social media platforms could be a way to raise their popularity much and motivate users better. It was observed by Salo et al. [33] that the recruitment of users for carbon calculators is a challenging task, but campaigns and visibility in the media have contributed to temporary peaks in the number of users.

2.3 Proposed labelling system

As mentioned in the previous section, graded labels are considered more effective than positive/negative labels. Therefore, the labelling system proposed here is comprised of eight coloured levels, a similar concept to the labels found on energy efficiency labels. These levels are familiar to users and incentivize them to improve their label by reducing their consumption or taking part in green initiatives such as the AURORA project. As the electricity and heating demand/production patterns in different European countries often differ significantly, each country will have a custom label where the baseline and the thresholds of each level will be determined according to average data specific to that country. It is suggested that the calculator initially only provides users with the overall label describing their overall consumption habits in order not to confuse or discourage them. After that, users will be able to view more detailed information about their energy rating such as separate labels for energy consumption and carbon footprint, and individual labels for each sector the calculator considers, such as transport, residential, etc. For those who are more intrigued, there would be an option to see the actual number in kWh or kg CO_2 emissions.

According to the European Climate Pact assessment documents, energy consumption should be reduced by 25% in households and by 16% in passenger transport by 2030, relative to the levels in 2015 [43]. Consequently, the baseline value established as average data of the label is from 2015 (see
Table *3*, Table 4, and Table 5) and we are creating a stepped system up to getting the Green Deal emissions/consumption objectives (Near-Zero). This way, we can include current behavioural data

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translated by the AURORA calculator, and measure how well individuals are performing to reach 2030 targets.

We do not know if becoming Near-Zero is a linear, exponential, logarithmic or stepped process. Definitively this is remarking the importance of the behavioural data to be collected by AURORA app within the citizen science initiative. In the meanwhile, the stepped ranking towards the Near-Zero Emissions Citizen, is aiming at promoting a quicker and easier shift; when people start to act, they can see how they change towards greener levels with small actions. Thus, the thresholds proposed for each level are set as described in Table 1.

As shown in Table 1, the average value in 2015 corresponds to the limit between level D and E in the labelling system. To become a Near-Zero Emissions Citizen (i.e. to reach level A or above), the energy consumption must be reduced by 25% of the average value (household consumption) and 16% (passenger transport consumption). On the other end of the scale, level G corresponds to an increase of 25% and 16% of the energy consumption in the household sector and transport, respectively.

Table 1 Limits for the labelling system

	Energy consumption	Transport
A+	[< -50% average value]	[< -50% average value]
A	[- 50% of the average value, - 25% average value]	[- 50% of the average value, - 16% average value]
B	[- 25% of the average value, - 10% average value]	[- 16% of the average value, - 9% average value]
C	[- 10% of the average value, - 5% average value]	[- 9% of the average value, - 5% average value]
D	[- 5% of the average value, average value]	[- 5% of the average value, average value]
E	[average value, +5% average value]	[average value, +5% average value]
F	[+5% of the average value, 25% average value]	[+5% of the average value, 16% average value]
G	[> -25% average value]	[> 16% average value]

It was debated among the consortium partners whether it is appropriate to apply the 2030 target (compared to 2015) as the near-zero emission benchmark (A in the labelling system) in a 3.5-year project. Although project AURORA ends in mid-2025, we believe using the 2030 target as the near-zero emission benchmark still makes sense. On the one hand, we do not expect a smooth transition to reach the 2030 target for all citizens across all of Europe (it is only the aggregated value of all citizens that will show a smooth transition), and the EU target for greenhouse gas emission reduction is expected to increase its ambition due to new policies and changing geopolitical situation. Consequently, some citizens will reach the 2030 target earlier than others. On the other hand, based on an initial assessment of data collected from the consortium (described in detail in Section 4 of the document), nearly 50% can reach the 2030 targets today without any interventions to change behaviour. One can argue that the consortium members are generally more conscious of energy issues and tend to have lower energy consumption than average, nevertheless, the preliminary analysis result also shows that the 2030 target is fairly achievable. As a result of this, and incorporating also the feedback from external reviewers, Level A+ is created on top of Level A, with even more ambitious targets (50% reduction compared to 2015 levels) for those citizens

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who find it easy to reach the 2030 targets. Both Level A and Level A+ will be considered as having achieved Near-Zero Emissions Citizens.

Table 2 summarizes the values of the label for different countries considering the different categories available. The final label will be the result of adding such values. To avoid confusion among citizens, we propose that two labels are presented upfront during the implementation in the mobile app: one for the overall energy consumption and one for the overall carbon emissions. In the app, citizens would be given the option to explore the breakdown of the overall consumption/emission in the three sectors, namely, electricity, heating, and transport. In the following section, the rationale for the threshold set at each level is explained.

Table 2 Definition of annual values for the labelling system

	Electricity Consumption		Heating consumption		Mobility		TOTAL	
	Energy demand (kWh)	Footprint (kg CO_2)	Energy demand (kWh)	Footprint (kg CO_2)	Energy demand (kWh)	Footprint (kg CO_2)	Energy demand (kWh)	Footprint (kg CO_2)
SPAIN								
A+	<804	<256	<1084	<219	<3011	<751	<4899	<1266
A	804-1205	256-383	1084-1627	219-329	3011-5059	751-1262	4899-7891	1266-1974
B	1205-1447	383-460	1627-1952	329-394	5059-5481	1262-1367	7891-8879	1974-2221
C	1447-1527	460-486	1952-2060	394-416	5481-5721	1367-1427	8879-9303	2221-2329
D	15271607	486-511	2060-2169	416-438	5721-6023	1427-1502	9303-9799	2329-2451
E	1607-1688	511-537	2169-2277	438-460	6023-6324	1502-1577	9799-10289	2451-2574
F	1688-2009	537-639	2277-2711	460-548	6324-6986	1577-1743	10289-11706	2574-2929
G	>2009	>639	>2711	>548	>6986	>1743	>11706	>2929
DENMARK								
A+	<911	<175	<3459	<740	<3572	<882	<7943	<1797
A	911-1367	175-262	3459-5189	740-1110	3572-6002	882-1482	7943-12557	1797-2855
B	1367-1640	262-315	5189-6227	1110-1333	6002-6502	1482-1605	12557-14368	2855-3253
C	1640-1731	315-332	6227-6573	1333-1407	6502-6788	1605-1676	14368-15091	3253-3415
D	1731-1822	332-350	6573-6919	1407-1481	6788-7145	1676-1764	15091-15885	3415-3595
E	1822-1913	350-367	6919-7264	1480-1555	7145-7502	1764-1852	15885-16680	3595-3774
F	1913-2278	367-437	7264-8648	1555-1851	7502-8288	1852-2046	16680-19214	3774-4334
G	>2278	>437	>8648	>1851	>8288	>2046	>19214	>4334
PORTUGAL								
A+	<604	<220	<819	<97	<2635	<653	<4058	<970
A	604-906	220-330	819-1228	97-145	2635-4428	653-1098	4058-6561	970-1572
B	906-1087	330-396	1228-1474	145-174	4428-4796	1098-1189	6561-7357	1572-1759
C	1087-1147	396-418	1474-1555	174-184	4796-5007	1189-1241	7357-7710	1759-1843
D	1147-1208	418-440	1555-1637	184-193	5007-5271	1241-1307	7710-8116	1843-1940
E	1208-1268	440-462	1637-1719	193-203	5271-5534	1307-1372	8116-8522	1940-2037
F	1268-1510	462-550	1719-2047	203-242	5534-6114	1372-1516	8522-9671	2037-2307
G	>1510	>550	>2047	>242	>6114	>1516	>9671	>2307
UK								
A+	<838	<318	<2436	<492	<3262	<819	<6536	<1629
A	838-1257	318-478	2436-3654	492-738	3262-5480	819-1375	6536-10391	1629-2591
B	1257-1508	478-573	3654-4385	738-886	5480-5937	1375-1490	10391-11830	2591-2949
C	1508-1592	573-605	4385-4628	886-935	5937-6198	1490-1555	11830-12418	2949-3095
D	1592-1676	605-637	4628-4872	935-984	6198-6524	1555-1637	12418-13072	3095-3258
E	1676-1760	637-669	4872-5115	984-1033	6524-6850	1637-1719	13072-13725	3258-3421

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F	1760-2095	669-796	5115-6090	1033-1230	6850-7568	1719-1899	13725-15753	3421-3925
G	>2095	>796	>6090	>1230	>7568	>1899	>15753	>3925
SLOVENIA								
A+	<807	<207	<2323	<274	<3214	<816	<6344	<1296
A	807-1211	207-310	2323-3485	274-411	3214-5399	816-1370	6344-10095	1296-2092
B	1211-1453	310-372	3485-4182	411-493	5399-5849	1370-1484	10095-11484	2092-2350
C	1453-1534	372-393	4182-4414	493-521	5849-6106	1484-1550	11484-12054	2350-2463
D	1534-1615	393-413	4414-4647	521-548	6106-6427	1550-1631	12054-12689	2463-2593
E	1615-1696	413-434	4647-4879	548-576	6427-6748	1631-1713	12689-13323	2593-2723
F	1696-2019	434-517	4879-5808	576-685	6748-7455	1713-1892	13323-15283	2723-3094
G	>2019	>517	>5808	>685	>7455	>1892	>15283	>3094

Source: own elaboration

Translating the values in Table 2 into a graded labelling system will lead to Figure 3. This figure shows the labelling system towards Near-Zero Emissions Citizens related to household energy consumption and passengers' transport energy consumption for the European Union (EU) and five selected countries. Energy consumption includes both electricity and heating consumption. Data shown in the figure is per capita per year.

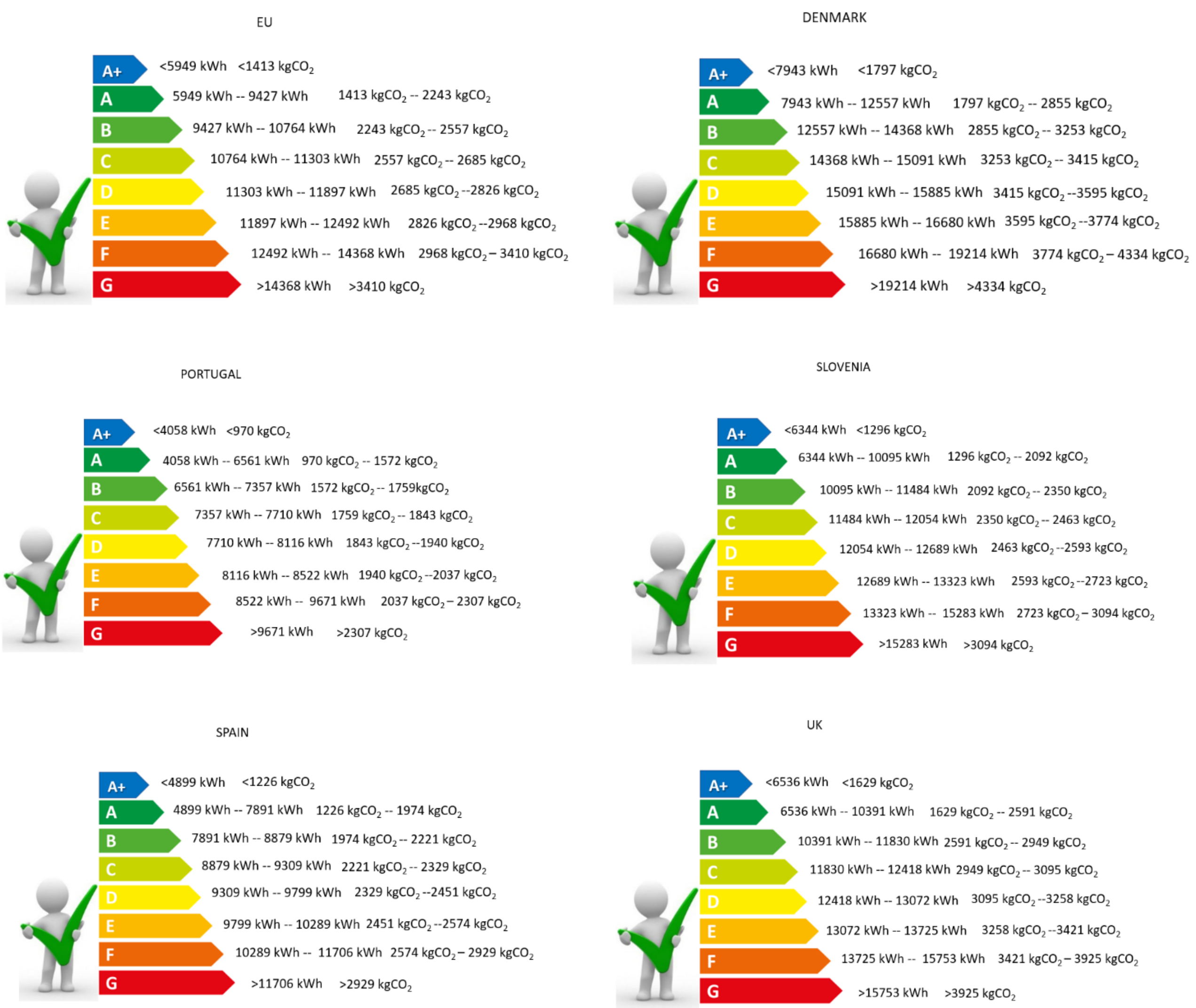

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Figure 3 AURORA labelling system towards Near-Zero Emissions Citizens related to household energy consumption and passengers´ transport energy consumption to achieve 2030 Climate Target Plan objectives. (a) EU data, (b) Denmark data, (c) Portugal data, (d) Slovenia data, (e) Spain data, (f) UK data [44].

From Figure 3a, we can observe that a European citizen becoming a Near-Zero Emissions citizen would need to have an average consumption lower than 9427 kWh by 2030. If we work with Spanish values (Figure 3e), a consumption lower than 9427 kWh would imply that a Spaniard could behave as in 2015 or previously, and will not contribute to the EU mission being Near-Zero Emissions. This is because, for example, the weather conditions are influencing the results regardless of citizens' behaviour. Similar discrepancies can be found in other countries: for example, in Portugal (Figure 2c), the Near-Zero Emissions implies a limit that is half of the Danish (Figure 2b) limit. The reason for this can be found in Table *2*: the Danish electricity consumption is like other countries but due to its climatic conditions they increase their heating consumption.

Because of that, our proposal is to have a set of thresholds defining the labels that are different for every country as a strategy to promote real behavioural changes. In that way, we would define a Near-Zero Emissions citizen according to the right column in Table 2 for each country, and potentially split them into three sub-labels as additional information for people who would like to find out the break-down. So, each citizen is well informed about his/her behaviour in different energy domains.

It should be noted that though the numbers here are quite ambitious, one might argue that they are still too large for the term 'near-zero' to be applicable. We are therefore also including a disclaimer in the AURORA app to clarify that 'near-zero' is a relative term and the total emissions for people with this label are still close to a ton of CO2 per year.

Some people may argue for a universal carbon emission level for citizens to become Near-Zero Emission Citizens. We believe keeping different emission values for the proposed Near-Zero Emission Citizen still makes sense, because we already notice the difference in emission factors associated with grid in these five demonstration countries (Table *3*). With the same amount of energy consumption, a citizen living in Spain will get a different emission, compared to a situation if he/she is living in Denmark. We hope this difference will inspire citizens to reflect on changes that are required on national level: why the other country's grid is cleaner than that in my country? Another example is with transport. Citizens cannot possibly switch to public transport to reduce their carbon emission, if no such facility is available in their region. This will hopefully lead citizens to another question: why are there no other options for transport available to me and my neighbours? The formation of these questions for people is itself a valuable process and it could eventually translate to a collective will to transform a region or country's energy sector towards more green sources. Even though AURORA promotes individual behavioural change among citizens, we reckon that institutional changes are as important and irreplaceable.

The difference in 'ability to change emissions' is of course not just limited to the transport options or electricity grid properties of a country. Many of the project participants will probably be students at one of the demo sites, who have much less choice over their housing and commute options due to low financial and scheduling flexibilities. This could also apply to others, but we believe that people who aren't able to change their lifestyle in the current time due to various reasons will still be able to learn about their emissions and hopefully implement changes at a later time.

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As a final point, it should be noted that even though two labels (one for energy and one for carbon emissions) might seem like an unnecessary complication, there is a reason we have opted to use a combined label instead of using either energy or carbon emissions as the default. Although reducing energy consumption and reducing carbon emissions could be seen as correlated variables, when talking of electrification and the use of green sources there is not a direct pattern. For example, people can move in electric vehicles or install domestic PV facilities at home and be proud of their greener footprint but at the same time, they could be increasing their energy consumption. However, we will not promote a sustainable and fair transition if our behaviour is not based on energy efficiency and responsible use of the resources at the time, on top of using greener sources as much as possible. Then, we must evaluate how important it is to be able to acquire information from citizens allowing us to analyse both, energy consumption and their emissions and classify them accordingly, in order to promote responsible patterns in a tentative label.

2.3.1 Proposed labelling system data and basic calculations

Within this chapter, we describe the data source of the values in the label. For the electricity grid calculations shown in Table 3, a constant emission factor is considered for each country. As for heating, shown in Table 4, the emission factor depends on the fuel type used for production of thermal energy in residents.

Table 3 Carbon footprint of domestic electricity consumption per capita for each country and the EU (2015 data). The electricity emissions factors reported here correspond to 2015, but the emissions factors used to estimate the label for every citizen correspond to 2020 and are reported in Table 6.

	Denmark	Portugal	Slovenia	Spain	UK	EU
a. Domestic electricity consumption per capita (kWh)	1822.06 kWh	1207.89 kWh	1614.92 kWh	1607.22 kWh	1675.94 kWh	1608.14 kWh
b. National electricity emission factor (g CO_2/kWh)	0.192 kg CO_2/kWh	0.364 kg CO_2/kWh	0.256 kg CO_2/kWh	0.318 kg CO_2/kWh	0.380 kg CO_2/kWh	0.317 kg CO_2/kWh
c. Electricity consumption carbon footprint (a*b) (kg CO_2)	349.84 kg CO_2	439.67 kg CO_2	413.42 kg CO_2	511.10 kg CO_2	636.86 kg CO_2	509.78 kg CO_2

Source: own elaboration (c) based on data from JRC (a) and Our World in Data (b)

Note: Five selected EU countries and the European Union´s carbon footprint of annual electricity consumption per capita are shown in Table 3. The calculation follows the equation (1). For both cases, the electricity consumption data is provided by IDEES-JRC [44], the emissions factor (EF), defined by IPCC [45] as "a coefficient that quantifies the emissions or removals of a gas per unit activity", for year 2015, is provided by Our World in Data [46].

Table 4 Domestic thermal energy consumption carbon footprint per capita for each country and the EU (2015 data)

	Denmark	Portugal	Slovenia	Spain	UK	EU
a. Domestic thermal energy consumption per capita -kWh-	6918.50 kWh	1637.29 kWh	4646.80 kWh	2168.76 kWh	4871.76 kWh	4693.68 kWh
b. Most common fuel type emission factor	District Heating using biomass	Biomass		Natural gas		
	0.214 kg CO_2/kWh	0.118 kg CO_2/kWh		0.202 kg CO_2/kWh		
c. Thermal energy consumption carbon footprint (a*b)	1480.56 kg CO_2	193.20 kg CO_2	548.32 kg CO_2	438.09 kg CO_2	984.09 kg CO_2	948.12 kg CO_2

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Source: own elaboration(c) based on JRC (a & b)

Note: The carbon footprint of the thermal energy consumption for 5 selected countries and the EU are shown in Table 4. Calculation of the emissions follows the equation (5). Data from thermal energy consumption per capita was found [44] and, in this case, the EF is associated with the type of fuel most used for heating households [47].

The electricity and heating consumption and the fuel emission factors are based on the JRC database, which we found to be the most comprehensive and updated database for European countries in regards to energy use. We have also chosen the most recent data (Our World in Data) to obtain the grid energy emission factors. It could also be possible to link the AURORA app to programs that provide live data for grid emission factors for better accuracy.

The carbon footprint calculation associated with passenger transport in the EU and the five selected countries is done. Table 5 shows such data [44]. Spain´s total energy consumption in 2015 was $2.8 \cdot 10^8$ MWh and it represented an amount of $6.98 \cdot 10^7$ t CO_2 emissions. Consumption per capita is easily calculated by dividing the energy consumption by the number of inhabitants; emission calculation follows the same process. Results show that annual energy consumption for a person living in Spain is 6023 kWh, and the emissions associated are 1502 kg CO_2. Results for the EU show an amount of 5596 kWh/capita for energy consumption, meaning 1368 kg CO_2/capita of emissions.

Table 5 Energy consumption and CO2 emissions for passenger transport (2015 data)

	Denmark	Portugal	Slovenia	Spain	UK	EU28
Total energy consumption (MWh)	4.04E+07	5.47E+07	1.33E+07	2.80E+08	4.23E+08	2.85E+09
Total CO_2 emissions (t CO_2)	9.99E+06	1.36E+07	3.37E+06	6.98E+07	1.06E+08	6.96E+08
Number of inhabitants	5659714	10374822	2062874	46449565	64875165	508504320
Energy consumption per capita (kWh/capita)	7145	5271	6427	6023	6524	5596
CO_2 emissions per capita (kg CO_2/capita)	1764	1307	1631	1502	1637	1368

Source: IDEES – JRC [44]

Note: The energy consumption considered in the passenger transport includes passenger road, rail and aviation data from IDEES-JRC.

2.3.2 Proposed labelling naming

In addition to the points already commented in the introduction, the importance of the grades, colours and positive reinforcement of the label cannot be neglected. So far, we have explained our stepped label following the product labels standards. The challenge of an identity label opens the door to think how we name these labels to make people feel more comfortable with them. Within the AURORA team, we made the exercise of thinking on different alternatives during the consortium meeting in Evora in May 2022. These go from animal scales (either size and speed), different grades of positive adjectives, a thermometer, weather forecast symbols (from cloudy to sunny), alphabet letters instead of current numerical system, a "Tamagotchi" or similar item like a plant that grows as citizens reduce their energy consumption/carbon emissions, and emoji system (sad to happy faces).

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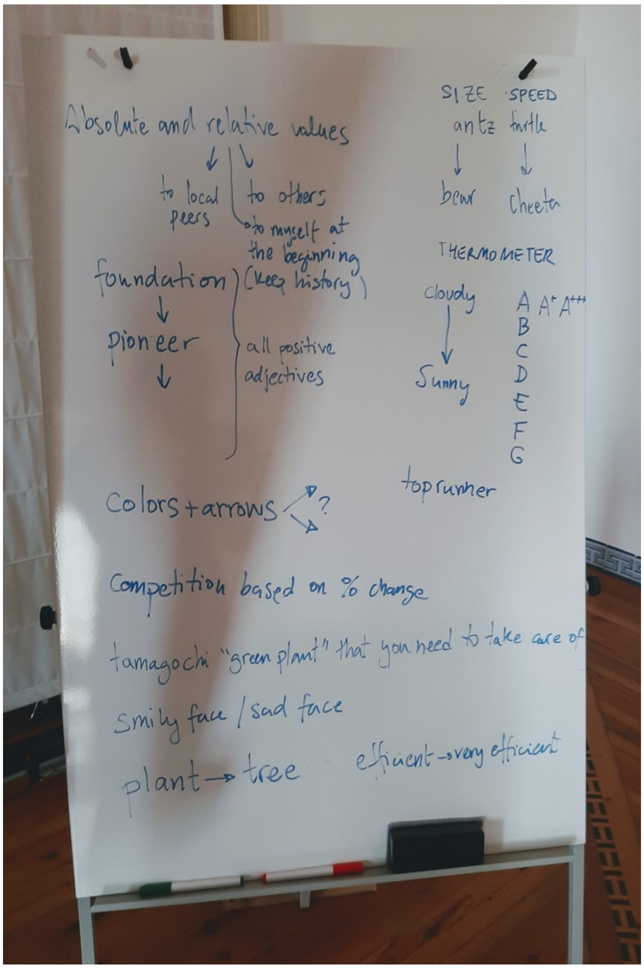

Figure 4 Picture of the name discussion that was conducted during the Consortium meeting in Evora (May 19, 2022)

Despite many options from the consortium brainstorming session, there was no clear winner as the preferred naming for the different labels. The following 3 options emerged as the possible options:

- Positive adjectives

The proposed names corresponding to the 5 levels from Level 4 (highest consumption/emission) to Level ZERO are: **Foundation, Pioneer, Transformer, Leader, Ambassador**. (note: at this point, the labelling was in 5 levels: Level 0-4. For Levels 1-4, there were sub-levels a and b, for example, 1a and 1b.).

- Alphabet letters with traffic light colouring

Similar to the more commonly seen energy efficiency labels, A-G with traffic light colouring is proposed, where A (green) denotes the least consumption/emission and G (red) refers to the most consumption/emission.

- Plants

Using plants to name the labels could add to the fun aspect of the labelling system, while on the other hand plants sequester CO_2 and therefore are more relevant to the emissions labels compared to others, e.g. animals. One example based on average height of plants could be: bush, palm, oak, pine, giant sequoia (choice of plants are for illustration purpose only), where the plant with smaller size refers to more consumption/emission, and the plant with bigger size refers to a lower consumption/emission.

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We also asked external experts on the review panel for their opinions on the names of the labels. Most of them prefer the option of alphabet letters with traffic light colouring, due to citizens' familiarity with its usage in energy labels. Experts note that other options using animals or plants might have negative implications in some culture, and it is difficult to choose species that are native to all demo countries. A few experts recommend associating positive names to the A-G letters, for example, Ambassador for A, Driver for D, Explorer for E, Founder for F, etc. At the time of writing this document, the names are still missing for B, C and G. It is noted some of these names may be difficult to translate to other languages in the future AURORA mobile app. In short summary, the consortium decides to adopt the A-G labelling name, together with the colour scheme, while the consortium continue to explore the option of adding positive names in the future mobile app.

3. CALCULATION METHODOLOGY FOR NEAR-ZERO EMISSIONS CITIZENS LABELS

Carbon footprint is a tool for measuring greenhouse gas (GHG) emissions produced when carrying out an activity. These emissions can be classified according to their origin as direct emissions (i.e. transport emissions) or indirect (i.e. emissions produced because of energy use, thermal and electricity) [48] [49] [50].

Carbon footprint calculation is essential to be aware of the effects on the climate change produced by the realization of different activities and to reduce and offset the footprint. Based on this, carbon footprint calculation is defined in equation (1), where activity data is the source of the emissions (fuel combustion, electricity, etc.) and EF is the emission factor related to that activity.

$$Carbon\ footprint\ (t\ CO_2) = activity\ data \cdot EF_{activity} \tag{1}$$

Source: IPCC [45]

In this report, three sectors for the carbon emissions calculation are defined: electricity consumption, thermal energy consumption, and transport. Since the AURORA label mainly considers energy and does not yet include purchases, food, or waste, we have decided to use kg-CO_2 as our carbon emissions unit instead of kg-CO_2e (CO_2 equivalent), as CO_2 is the main GHG in these sectors that are considered in the calculation.

Based on the previous review on existing footprint calculators, the proposal for AURORA is based on prioritizing the simplicity of the calculation while capturing the most important indicator for energy consumption.

Since the final goal is to encourage citizens to reach Green Deal goals, while the baseline values of the label are referring to the 2015 data and thresholds were established to reach the 2030 targets. The calculation must include the most updated data values of the different variables to have a clearer picture of the current state-of-the art. While for fuels this is a constant value, this is of special importance for instance in national emissions factors.

The energy consumption and its related carbon emissions calculation will be done through the AURORA app, which is referred to as the "calculator" in the sections below.

3.1 Carbon footprint calculation for the electricity consumption

The calculation follows the equation (2).

$$\text{Carbon Footprint}_{\text{electric consumption}} = {\text{electric consumption}}/_{\text{capita}} \cdot \text{EF}_{\text{electric consumption}} \tag{2}$$

Source: IPCC [51]

To evaluate citizen's behaviour, requested data would be the electricity consumption (kWh), the period tracked of that consumption (days, months…), and the number of members per dwelling. The carbon footprint for electricity consumption is calculated with this information and the EF of the country where the person lives.

An alternative method for electricity consumption carbon footprint could be calculated with data from the electricity provider. Knowing the provider´s EF and multiplying by the electricity consumption is easy to calculate the carbon footprint. However, it is not worthy to calculate the carbon footprint that way because the provider´s data should be adjusted each year and it makes the calculation more difficult, so this alternative method is discarded.

Therefore, it could be argued that the AURORA methodology that is based on considering national emission factors is punishing people who owns their own renewable installations or choose green providers. The first point will be overcome in the AURORA footprint calculator since "green energy production" (from the crowdfunded solar installation in which citizens could join in every country) will be reduced from the personal footprint (explained in the sections below). On top of that, if a user of the carbon footprint calculator owns a domestic solar PV installation, the user could provide the installed capacity to the calculator so that the green energy production from this calculator is also taken into consideration.

3.2 Deducting from our electricity footprint the renewable energy produced at domestic or communitarian level

The carbon footprint calculation of green electricity production follows equation (3), where the carbon footprint associated with the electricity produced by photovoltaic (PV) facilities is subtracted from the carbon footprint associated for the same energy if this is produced by the national energy production mix (it is calculated with the EF of the total energy production from Table 6).

The fact that the PV emissions are negative is because they are counteracting the conventional energy production emissions. The carbon footprint calculation for PV energy production follows the equation (4), where the emission factor of the PV energy production is multiplied by the electricity produced by this PV source. Data for this calculation should stay as updated as possible, and the EF for the generation of PV energy is the same for all countries [47].

$$\text{Carbon footprint}_{\text{energy prod}} = \text{Carbon footprint}_{\text{others energy prod}} - \text{Carbon footprint}_{\text{PV energy prod}} \quad (3)$$

$$\text{Carbon footprint}_{\text{PV energy prod}} = \text{Energy produced}_{\text{PV}} \cdot \text{EF}_{\text{PV energy prod}} \quad (4)$$

Table 6 Carbon emission intensity of electricity generation

	Denmark	Portugal	Slovenia	Spain	UK	EU
Energy production EF(1)	0.116 kg CO_2/kWh	0.201 kg CO_2/kWh	0.219 kg CO_2/kWh	0.190 kg CO_2/kWh	0.209 kg CO_2/kWh	0.226 kg CO_2/kWh
Photovoltaic electricity production EF	0.0305 kg CO_2/kWh(2)					

Source: own elaboration based on data from Our World in Data 2020 and JRC

(1) Data for the emission factor of the energy production is from 2020, the most recent data provided [46].
(2) Data from JRC [47] (Table 3, reference Amponsah et al., 2014. Suggested LCA EF or LCA EF average).

To evaluate the footprint saved due to green electricity investments we should ask people for the following information:

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- In the case of AURORA facilities: their own investment (€). QPV (the AURORA partner responsible for monitoring the rooftop PV installations) will provide the information on the electricity produced by PV and the period of such measurement. Knowing the installed power, AURORA can evaluate the share of each people in the global facility. Thus, the system would be able to make the calculation of saved footprint.
- In the case of external facilities: the user should either provide the production of their PV panels or the installed capacity of the installation and its location. The app will then calculate the energy produced by such installation in the second case. With all the calculations made and the requested data from citizens we will be able to know both electricity consumption (kWh) and automated footprint calculation. For the footprint calculation, we must consider that the footprint saved due to green electricity investments (equation 5) must be deducted from equation 2. Thus, we can now rank people's emissions in our label according to their electricity-related behaviour.

3.3 Carbon footprint calculation for the thermal energy consumption

This section explains the calculation for the thermal energy consumption carbon footprint (equation [5]).

$$\text{Carbon footprint}_{\text{thermal energy}} = {}^{\text{heating thermal consumption}}/_{\text{capita}} \cdot \text{EF}_{\text{fuel}} \tag{5}$$

Source: IPCC [51]

The requested data would be the thermal energy consumption (kWh), the period tracked of that consumption (days, months…), the number of members per dwelling, and the type of heating fuel used. The carbon footprint for thermal energy consumption is calculated based on this information. Table 7 shows the emission factor for different heating fuels used in households [47]. Furthermore, heating generation can come from different sources such as renewable energy sources or fuel combustion. Some renewable energy sources (Table 8) used for heat generation are geothermal, solar collectors, biomass, etc. It is also noted that there are different types of heating technologies, such as district heating, underfloor heating, radiant heating, heat pumps, electric heaters. It is good for researchers to know the different heating technologies people are using in their households because it can help understand the heating consumption and make recommendations for reducing this consumption, even using the same energy source. Then it would be recommendable to request the kind of heating technology used in the dwelling to better understand the energy consumption.

Table 7 Heating fuels emission factors

	EU
Fuel	Emission factor (kg CO_2/kWh)
Heating oil	0.267
Natural gas	0.202
LPG (liquefied petrol gas)	0.227

Source: own elaboration based on JRC

Table 8 Heating renewable energy sources emission factors

Renewable energy source	Emission factor (kg CO_2/kWh)
Biomass(1)	0.118
Locally-produced biomass	0.000
Geothermal	0.050

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Solar thermal	0.040
District heating(2)	0.268

Source: own elaboration based on JRC and IEA

(1) Data calculated by the average value of the LCA emission factor from JRC. The challenge here is that emissions depend on the type of biomass and, more importantly, the distance that that biomass has been transported before being used. This makes the calculation of emissions for biomass very difficult and reported values are variable from source to source. In Denmark, agriculture residues produced locally are used to produce heat. Hence, there is another source as “locally-produced biomass” that has lower EF.

(2) District heating EF by default is calculated based on a relation from IEA [52] considering coal, natural gas, heating oil, electricity, renewables (solar thermal and geothermal) and others (biomass and waste treatment) as energy sources, values are calculated from JRC data. If the certain source for district heating is known, then the EF applied is the one corresponding to that energy source. For instance, in Denmark most of the district heating comes from locally-produced biomass, hence the assumed emission factor is zero. The rest of the data is from JRC [47]: Amponsah et al., 2014. Suggested LCA EF or LCA EF average.

In the case of using renewable heating energy sources, it is slightly different from estimation made for electricity consumption and the use of electric renewable sources. In the previous section, we assume the footprint of the electricity consumption linked to the national emission factor and, subsequently we deduct from it the emission footprint that is related to the crowdfunded solar installation and production of other domestic or collective renewable energy facilities that the citizen has. Now the footprint related to the heating system is not linked to a national emission factor but to personal consumption and fuel used. So, if the citizen is using i.e. geothermal, the carbon footprint is directly calculated with the equation (5) despite of being “renewable”. The exception is electric heating systems, which must be calculated following the instructions in the previous section and request people to include the electricity consumption data (including that part of the electricity is used for heating).

When setting up the AURORA system, we should think how to ask for the data. We must consider that some people may use hybrid systems for heating and even have different energy sources for hot water and heating the house. Furthermore, users will be warned that the calculator is based on averages of a year, so entering data from only a short period, such as a week during winter, could lead to a slightly skewed calculation and result in a better/worse label than if they used short periods from different seasons, such as summer and winter, or if they tracked usage for a longer period of time.

With all the calculations made and the requested data to citizens we will be able to know both energy consumption (kWh) and automated footprint calculation. So that these can be included into the label.

3.4 Carbon footprint calculation for passengers´ transport energy consumption

The carbon footprint for passenger transportation is more complicated than the electricity and heating calculations. The carbon footprint for the transport sector is determined by the type of vehicle used (public or private), the energy source (fuel, electricity), and its energy consumption per travelled distance. Table 9 shows data for passenger transport [44].

A description of the calculation of energy consumption per travelled kilometre and passenger is explained in the following lines. The carbon footprint calculation follows equation (6), where the EF depends on consumed fuel. Data requested would be the type of vehicle used, its energy source, and the travelled distance. According to this data, the CO_2 emissions for each trip are calculated.

$$Carbon\ footprint_{transport} = Energy\ consumption\ \left(\frac{MWh}{Km}\right) \cdot EF_{energy\ source}\left(\frac{t\ CO_2}{MWh}\right) \cdot Traveled\ distance(Km) \tag{6}$$

Source: own elaboration based on IPCC

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The main concern when applying this formula for a citizen science project is that people might not know which fuel or energy consumption corresponds to the public transport that they use. This could be an obstacle to engage people in the AURORA footprint calculator. Therefore, we must look for an alternative. Then equation (7) can serve such purpose.

$$Carbon\ footprint_{transport} = EF_{vehicle} \cdot Traveled\ distance \tag{7}$$

Source: European Environment Agency [52]

In Tables 10 and 11, considering data from Table 9, we have prepared the required emission factors. These are the required vehicles emission factors when applying equation (7). To that end and considering that AURORA is a "personal" trainer we have managed emission factors so this can be individualized and expressed by "passenger". In the following lines, we explain the effect of "occupancy" on the emission factors of the vehicles.

The vehicle occupancy must be taken into account, because the vehicle emissions must be divided by the number of passengers, resulting in lower emissions per capita when sharing transport (private and public). When talking about cars, higher occupancy means higher fuel consumption because the vehicle mass is higher too. This is translated into higher emissions, but when talking about passengers, the consumption per passenger is lower and the carbon emissions per passenger are lower too. In Fontaras et al., the reference vehicle mass (driver + fuel) is 100 kg. An additional 100 kg load is reported to increase fuel consumption from 0.3-0.5 L/100km, meaning an increase of 7.5-12.5 g CO_2/km [53]. Following the calculation, for a full car, for example, the total mass increases by 240 kg, resulting in 0.0096 L fuel/km and 24 g CO_2/km higher than the reference mass. As can be seen, fuel consumption and carbon emissions increase when car occupancy is higher. Despite this slight increase, emissions per passenger are substantially lower when carpooling.

Electricity consumption also increases with occupancy. In this case, in literature the reference mass is for 1 passenger is 70 kg, and increasing mass by 100 kg means an increase in electricity consumption of 0.4-1.3 kWh/100 km, which means 1.2 – 3.8 g CO_2/km higher, meaning 300 g CO_2/kWh [54]. Calculating for cars and motorcycles, one person load means an increase of 70 kg, meaning an increase of 0.595 kWh/100km of electricity consumption and 1.75 g CO_2/km of emissions. This data supposed an increase of carbon emissions to 294.117 g CO_2/kWh.

This increase in energy consumption and emissions is considered only for private vehicles (cars, motorcycles...). In the case of public transport, we did not consider any increase in energy consumption and emissions when increasing the mass load. The calculation for public transport was done by dividing the total energy consumption and emissions per vehicle by the number of passengers according to the occupancy. Depending on the occupancy, the number of passengers in public transport is calculated according to a normal distribution with the average of passengers per travelled kilometre from IDEES-JRC data. Three categories are defined: almost empty (15.9% of occupancy), average, and nearly full (84.1% of occupancy). Fuel and electricity consumption depending on the level of occupancy for public transport is shown in Table 10. Table 11 shows the same calculation but for Spain´s case.

For the urban bus case, we have considered different types of buses: electric bus, hybrid-electric bus, alternative fuel bus (powered by natural gas, LPG, and biofuels), diesel bus and the default bus. This categorization is done because in some situations citizens may be able to find out how the bus is powered. When selecting the type of bus, the emissions may be reduced. The calculation

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for the different types of buses is explained as follows: the energy consumption for all the bus choices is the same because all consume the same energy independently of the fuel used, and this data is taken from JRC. For the emissions, we must consider the energy source: the default bus is calculated following the relation done by ACEA [55], and for the rest of the cases, the energy consumption is multiplied by the EF of the energy source to calculate the emissions. These EFs are shown in Table 12 and are country specific.

Although some similar calculations on vehicle's emissions per kilometre have already been conducted for different countries, which are naturally close to the obtained transport emission factors here, we chose to construct our own database to ensure uniform assumptions and clarity for all five countries.

As aviation is a major source of carbon emissions within the transport sector, air travel is also included in the calculator by defining consumption and carbon emissions of a single flight per person. For the first version, this number does not take the difference between long-haul and short-haul flights into consideration and instead an average flight distance travelled by the citizens of each demo site is used to calculate the final consumption and emissions, as shown in Table 13. Those values are calculated by dividing the energy consumption per flight by the load of the flight (number of passengers per flight) to have the results in kWh per capita. The same calculation is done for the CO_2 emissions to have kg CO_2 per capita. All these values come from IDEES-JRC and are country-specific. Although this assumption might cause an over estimation in some cases, we consider it a good tool for raising awareness among citizens about the high CO_2 cost and even higher effect on the atmosphere warming caused by flying.

Table 9 Passenger transport data for Spain and the EU (2015 data)

	Spain	EU28
ROAD TRANSPORT		
Load factor vehicles (p/movement)		
Motor coaches, buses, and trolley buses	23.74	19.29
Vehicle-efficiency-effective (kWh/km)		
Fuel powered-2-wheelers	0.4385	0.4257
Passenger cars		
Fuel cars	0.7583	0.6972
Plug-in hybrid-electric	0.3826	0.4524
Battery electric vehicles	0.3268	0.3361
Electric motorcycles(5)	0.1322	0.1360
Electric bikes(5)	0.0119	0.0122
Electric scooters(5)	0.0257	0.0265
Motor coaches, buses, and trolley buses	6.0813	6.0732
Emission factor (kg CO_2/kWh)		
Fuel (6)	0.254	0.249
Diesel	0.257	0.252
Petrol	0.240	0.241
Electricity	0.190	0.226
RAIL, METRO, AND TRAM		
Load factor vehicles (p/movement)		
Metro, tram, and urban light rail	70.1	76.1
Electric and diesel passenger trains	67.7	114.5
High-speed passenger trains	272.9	283
Vehicle-efficiency (kWh/km)		
Metro, tram, and urban light rail	5.0009	4.7334

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Electric passenger trains	18.829	15.6656
Diesel passenger trains	27.749	19.224
High-speed passenger trains	27.8882	24.6323
Emission factor (kg CO_2/kWh)		
Electricity	0.190	0.226
Diesel (for diesel trains)	0.267	0.264
AVIATION		
Energy consumption per flight (kWh/p)	369	423.53
CO2 emissions per flight (kg CO2/p)	95.437	109.622
WALKING	0	0
BIKE	0	0

Source: IDEES-JRC

(5) Calculations follow a relation created in base to Weiss et al. (2020) data [54].
(6) Fuel EF taken is data from fuel EF in general for passenger transport (JRC data).

Table 10 Energy consumption and emission factor per passenger and kilometre (EU data)

Type of vehicle	Vehicle consumption per passenger according to vehicle occupancy					Units (7)	Emission factor per passenger according to vehicle occupancy					Units
	1	2	3	4	5		1	2	3	4	5	
Fuel car	0.693	0.363	0.252	0.197	0.164	kWh/p-km	0.1722	0.0653	0.0475	0.0387	0.0335	kg CO_2/p-km
Electric car	0.336	0.171	0.116	0.089	0.072	kWh/p-km	0.0760	0.0133	0.0093	0.0072	0.0060	kg CO_2/p-km
Plug-in hybrid electric car(8)	0.452	0.235	0.162	0.126	0.104	kWh/p-km	0.1073	0.0252	0.0174	0.0135	0.0112	kg CO_2/p-km
Motorcycles and mopeds	0.426	0.229	-	-	-	kWh/p-km	0.1058	0.0260	-	-	-	kg CO_2/p-km
Electric motorcycle(9)	0.136	0,068	-	-	-	kWh/p-km	0.0307	0.0022	-	-	-	kg CO_2/p-km
Electric bike(9)	0.012	-	-	-	-	kWh/p-km	0.0028	-	-	-	-	kg CO_2/p-km
Electric scooter(9)	0.027	-	-	-	-	kWh/p-km	0.0060	-	-	-	-	kg CO_2/p-km
-	Almost empty		Average	Nearly full		-	Almost empty		Average		Nearly full	-
Urban bus (by default)	0.9901		0.3148	0.1872		kWh/p-km	0.2428		0.0772		0.0459	kg CO_2/p-km
Electric bus						kWh/p-km	0.2238		0.0712		0.0423	kg CO_2/p-km
Hybrid-electric bus						kWh/p-km	0.2366		0.0752		0.0447	kg CO_2/p-km
Diesel bus						kWh/p-km	0.2494		0.0793		0.0472	kg CO_2/p-km
Alternative fuels bus						kWh/p-km	0.2257		0.0718		0.0427	kg CO_2/p-km
Subway, tram and urban light rails	0.1956		0.0622	0.0370		kWh/p-km	0.0442		0.0197		0.0117	kg CO_2/p-km
Electric passenger trains	0.4474		0.1423	0.0846		kWh/p-km	0.1011		0.0322		0.0191	kg CO_2/p-km
Diesel passenger trains	0.5491		0.1746	0.1038		kWh/p-km	0.1449		0.0461		0.0274	kg CO_2/p-km
High-speed trains	0.2737		0.0870	0.0575		kWh/p-km	0.0619		0.0197		0.0117	kg CO_2/p-km
Plane	423.53					kWh/p	0.1096					kg CO_2/p

Source: own elaboration based on IDEES-JRC data

(7) For the passenger consumption some simplifications are done: 1 L fuel = 1 g fuel; 1 L fuel = 10 kWh [56]
p-km: passenger-km

(8) For the calculation of the consumption and emissions for hybrid cars, the following approximation has been done: 50% of fuel consumption + 50% of electricity consumption.

(9) Calculations for electricity consumption for electric vehicles have been done according to a relation between data from Weiss et al. [54]. In this paper, electricity consumption for electric vehicles is shown, but when comparing this data with JRC data for electric cars, results are not comparable, so a relationship between the electric vehicles in the paper is done and applied to the JRC electric car data

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Table 11 Energy consumption and emission factor per passenger and kilometre (Spain data)

Type of vehicle	Vehicle consumption per passenger according to vehicle occupancy					Units	Emission factor per passenger according to vehicle occupancy					Units
	1	2	3	4	5		1	2	3	4	5	
Fuel car	0.748	0.390	0.271	0.211	0.175	kWh/p-km	0.1897	0.0771	0.0557	0.0451	0.0388	kg CO_2/p-km
Electric car	0.327	0.166	0.113	0.086	0.070	kWh/p-km	0.0621	0.0107	0.0075	0.0059	0.0049	kg CO_2/p-km
Plug-in hybrid electric car	0.383	0.200	0.139	0.108	0.090	kWh/p-km	0.0849	0.0170	0.0118	0.0092	0.0077	kg CO_2/p-km
Motorcycles and mopeds	0.439	0.235	-	-	-	kWh/p-km	0.1112	0.0280	-	-	-	kg CO_2/p-km
Electric motorcycle	0.132	0.066	-	-	-	kWh/p-km	0.0251	0.0018	-	-	-	kg CO_2/p-km
Electric bike	0.012	-	-	-	-	kWh/p-km	0.0023	-	-	-	-	kg CO_2/p-km
Electric scooter	0.026	-	-	-	-	kWh/p-km	0.0049	-	-	-	-	kg CO_2/p-km
-	Almost empty		Average		Nearly full	-	Almost empty		Average		Nearly full	-
Urban bus (by default)	0.8056		0.2562		0.1523	kWh/p-km	0.1918		0.0610		0.0363	kg CO_2/p-km
Electric bus						kWh/p-km	0.1531		0.0487		0.0289	kg CO_2/p-km
Hybrid-electric bus						kWh/p-km	0.1801		0.0573		0.03421	kg CO_2/p-km
Diesel bus						kWh/p-km	0.2071		0.0659		0.0392	kg CO_2/p-km
Alternative fuels bus						kWh/p-km	0.1837		0.0585		0.0347	kg CO_2/p-km
Subway, tram and urban light rails	0.2243		0.0713		0.0424	kWh/p-km	0.0427		0.0136		0.0081	kg CO_2/p-km
Electric passenger trains	0.9026		0.2870		0.1707	kWh/p-km	0.1715		0.0545		0.0324	kg CO_2/p-km
Diesel passenger trains	1.3302		0.4230		0.2515	kWh/p-km	0.3546		0.1128		0.0670	kg CO_2/p-km
High-speed trains	0.2868		0.0912		0.0542	kWh/p-km	0.0545		0.0173		0.0103	kg CO_2/p-km
Plane	369					kWh/p	0.0954					kg CO_2/p

Source: own elaboration based on IDEES-JRC data

Table 12 Emission Factors for the different urban bus choices

Type of bus	Denmark	Slovenia	Portugal	Spain	UK	EU
Bus (by default)	0.230 kg CO_2/kWh	-	0.242 kg CO_2/kWh	0.238 kg CO_2/kWh	0.254 kg CO_2/kWh	0.245 kg CO_2/kWh
Electric bus	0.116 kg CO_2/kWh	-	0.201 kg CO_2/kWh	0.190 kg CO_2/kWh	0.209 kg CO_2/kWh	0.226 kg CO_2/kWh
Hybrid-electric bus	-	-	-	0.224 kg CO_2/kWh	-	0.239 kg CO_2/kWh
Alternative fuels bus	-	-	0.228 kg CO_2/kWh			
Diesel bus	0.242 kg CO_2/kWh	0.262 kg CO_2/kWh	0.248 kg CO_2/kWh	0.257 kg CO_2/kWh	0.261 kg CO_2/kWh	0.252 kg CO_2/kWh

Source: own elaboration based on ACEA (based on the percentage of the different bus choices for each country), JRC (the EF for natural gas, LPG and biofuels used for the alternative fuels buses), IDEES-JRC (for the national diesel EF, used for the diesel and hybrid buses) and Our World in Data (for the electricity EF) data

Note: not all countries have the same bus options.
For the hybrid-electric EF a 50% of diesel and 50% of electricity is calculated.
For the alternative fuels EF, an average of the natural gas, biofuels and LPG EF is calculated. Data come from JRC and is the same for all countries.

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Table 13 Energy consumption and emissions for aviation per flight per capita

Country	Denmark	Slovenia	Portugal	Spain	UK	EU
Consumption (per flight per capita)	343.4 kWh/ passenger	216.1 kWh /passenger	363.3 kWh /passenger	369.0 kWh /passenger	547.2 kWh /passenger	423.5 kWh /passenger
Emissions (per flight and per capita)	88.9 kg CO_2 /passenger	55.9 kg CO_2 /passenger	94.5 kg CO_2 /passenger	95.4 kg CO_2 /passenger	141.6 kg CO_2 /passenger	109.6 kg CO_2 /passenger

Source: own elaboration based on data from IDEES-JRC

3.5 Total carbon footprint

Finally, the final carbon footprint calculation follows the equation (8) where all the carbon footprints (CF) mentioned before are considered.

$$Carbon\ footprint_{total} = CF_{electric\ cons} + CF_{heating\ cons} + CF_{transport\ cons} - CF_{energy\ prod} \quad (8)$$

4. PRELIMINARY ANALYSIS AND INITIAL ASSESSMENT OF THE LABELS

A preliminary analysis to study the labelling system and to verify our approach to the calculation has been done. A spreadsheet version of the calculator was circulated among consortium partners to collect data from the demonstrator sites. To have a representative sample for each of the countries of our study (Denmark, Portugal, Slovenia, Spain, UK and EU) it was necessary to involve 45-50 people. Table 14 shows the number of answers received for each country. Due to the low number of responses (less than 7), Portugal and UK are not studied in detail during this initial assessment. So, in the next sections the energy consumption and the emissions at the household level and passenger transport are explained for all the cases, and specifically for Denmark, Slovenia and Spain.

Table 14 Number of answers from each country

Country	Number of answers
Denmark	8
Portugal	6
Slovenia	8
Spain	15
UK	6
EU	2
TOTAL	45

It is worth mentioning that in this analysis, level 0 corresponds to Level A and A+ in the labelling system described in Section 2. Level 1a, 1b, 2a, 2b, 3 and 4 correspond to Level B, C, D, E, F, G respectively. This is because this preliminary analysis was implemented with the initial proposal for the labelling scheme that was subsequently modified following suggestions from reviewers and the result of this analysis.

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4.1 Energy consumption

The energy consumption was analysed for the household and passenger transport data. Data for the energy consumption at the household level is provided from the energy bill and the energy meters and data for the transport consumption is provided by users inputs regarding the distance travelled and choosing the type of transport used. The main results (Figure 5) show that many of the respondents belong to **level 0** (22 people) and **level 4** (10 people). The former is one of the reasons that lead as to propose a more ambitious category (named as A+). It is important to remark the fact that as some of the respondents did not provide information about household or transport data, these cases are considered as "**no data**".

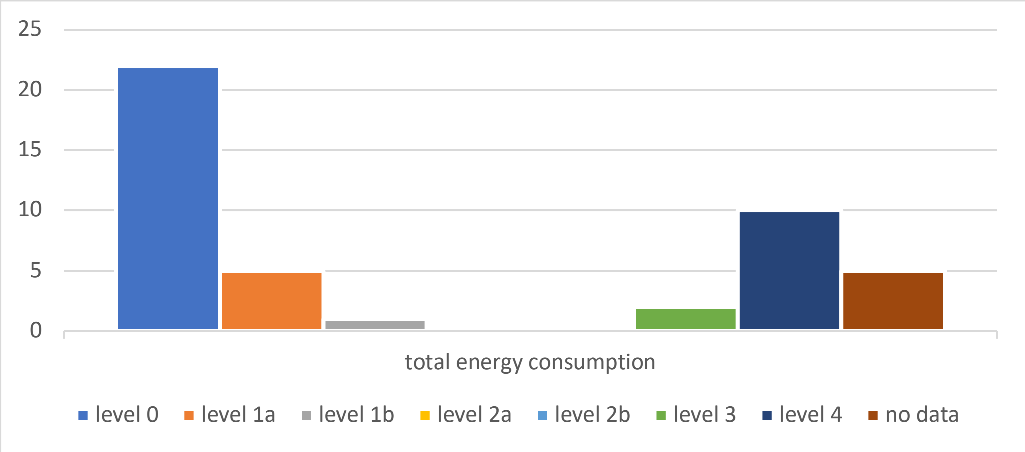

Figure 5 Number of people belonging to each of the levels in total energy consumption

If we study separately for those countries whose number of responses is reliable, for Denmark we can see that 6 people belong to **level 0** while the 2 other respondents have an incomplete analysis because they did not provide household data. In the Slovenian case, 3 people belong to level 0, 2 people belong to **level 4**, and there are other 3 cases of incomplete household data. Finally, for Spain, the level most observed is **level 0** with 7 people, followed by **level 4** with 4 people, there are other levels with lower numbers of occurrence (**level 1a, 1b** and **3**).

4.1.1 Electricity consumption

In the electricity consumption, there is representativeness of each of the levels, with **level 4** being the most reported with 16 people belonging to it and followed by **level 0** with 9 people and **level 1a** (7 people).

It is important to consider that some people are providing thermal consumption as electric heating, so the consumption for these people increases and should not be considered as electricity consumption alone and it should account all for the household consumption.

Talking about countries, people from Denmark belong to various levels (**level 0, 1a, 1b and 4**) and 2 people have incomplete household data. People living in Slovenia belong to **level 4** (5 people) and **level 2a** (1 person), while data is incomplete for 2 cases. People from Spain reach most of the levels being **level 4** the most occupied (6 people) and **level 0** (4 people), and people also belong to **levels 1a, 2b** and **3**.

4.1.2 Thermal consumption

On the other hand, with the thermal consumption data analysis, we found many problems. These problems are derived from not being able to access the thermal data (i.e., central heating), and no

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information on the thermal consumption provided (with no observations noted by the respondents). Most of these people have district heating as a thermal source. We understand from the Danish project partner that retrieving district heating data in Denmark could be a troublesome task for people living in rented apartment, since the cost (and consumption) of heating is usually included in the rental fee. Though most data can be tracked online, the household owner is required to log in or give permission for data access, making it more troublesome for users to provide thermal consumption data. As a result, the next step to consider is how we can address this particular challenge for thermal calculation. This will also be relevant for the mobile app development in the future, as we expect automatic data retrieval through an API if it is possible.

Those cases where thermal consumption is provided are analysed in the following lines. From Denmark, only 2 participants have thermal data and they belong to **level 0**. Participants living in Slovenia belong to **level 0** and **level 4** (3 people's data missing) and excluding 2 cases where they specified that they have electric heating. Spanish participants belong to **level 0** (7 people) and **level 4** (1 person) while 5 people are considered as "no data" (excluding 2 cases of electric heating).

4.1.3 Household consumption

Here, both the electricity and thermal consumption are considered together to have one household label. In some cases, as explained before, this is the label that must be considered due to the lack of thermal heating data because they have an electric heating source.

In household consumption, the level where most people belong is **level 0** (18 people). It is important to clarify that regarding the lack of thermal consumption 17 people are considered as "**no data**" until we figure out solutions to the challenge with thermal data retrieval and clarify whether the electricity consumption data includes thermal data.

For the specific country data, 2 Danish people belong to **level 0** while 6 people are considered as "**no data**" because of the lack of the data provided by people. People from Slovenia belong to **level 0** (4 people) while 1 person belongs to **level 4**, 3 people are considered as "**no data**" due to the lack of thermal data or incomplete household data. Spanish people belong to **level 0** (7 people), and **level 1a** and **level 4**, 5 people did not provide thermal consumption and therefore are considered as "**no data**".

4.1.4 Transport consumption

Finally, the transport consumption is analysed using the distance travelled, which is then converted into kWh with information on the type of vehicle used. 24 people belong to **level 0**, followed by 16 people in **level 4**, 3 people in **level 1a** and 2 people belong to **level 2a**.

Analysing by country, people from Denmark belong to **level 0** (6 people), **level 2a** (1 person) and **level 4** (1 person), they use different types of transport: the most used being bike and passenger trains. Slovenian people belong to **levels 0** (4 people), **4** (3 people) and **1a** (1 person); they typically travel by fuel car and electric vehicles. People from Spain belong to **level 0** (7 people), **level 4** (6 people) and **level 1a** (2 people); the most-used vehicle is fuel car and a lot of people combine public and private transport on their trips.

4.2 Emissions related to the energy consumption

On the other hand, we have to analyse the CO_2 emissions related to energy consumption. For the calculation, an emission factor is needed (explained in section 3). 5 people are considered "**no**

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data" due to the lack of data. 24 people belong to **level 0**, followed by 9 people in **level 4**. There is at least one person belonging to each level (except for level 2a), see Figure 6.

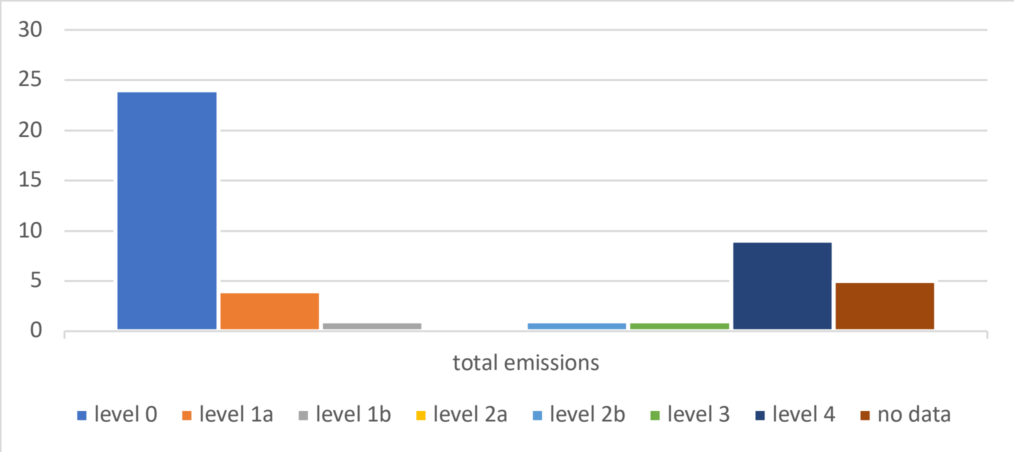

Figure 6 Number of people belonging to each of the levels in total emissions

Analysing separately the different countries, we observe that people from Denmark belong to **level 0** (4 people) and **level 1a** (2 people), while 2 people are considered as "**no data**". People from Slovenia belong to **level 0** (3 people), **level 4** (2 people) and 3 of the respondents are considered as "**no data**". Finally, Spanish participants belong to different levels, being **level 0** (9 people) the most reached level, and **levels 1a** (1 person), **1b** (1 person), **2b** (1 person), **3** (1 person) and **4** (2 people) are also observed.

4.2.1 Electricity emissions

About the electricity emissions label, 22 people reached **level 0**, followed by **level 4** with 10 people, and other levels are reached too. The emissions are related to the electricity emission factor of the country where people live. It is worth mentioning that this initial calculation does not consider the renewable facilities people own.

For Denmark, 5 people belong to **level 0** and 1 person to **level 2a** (2 people are classified as "**no data**" due to the lack of household data). People from Slovenia belong to **level 4** (5 people) and **level 1a** (1 person), while 2 people are considered as "**no data**" because they have their household data incomplete. Spanish people belong to different levels, being **level 0** the most occupied (9 people), followed by **level 4** (3 people), and **levels 1a**, **1b** and **3**, with 1 person belonging to each level.

4.2.2 Thermal emissions

In this case, as mentioned before, we have to remark that 17 people belong to "**no data**" and 17 people are in **level 0**.

For Danish people, as mentioned before, we have 6 cases of "**no data**", 1 person in **level 0** and 1 person in **level 4**. Slovenian people belong to **level 0** (2 people) and **level 4** (1 person) while 3 people are considered as "**no data**" and 2 are excluded because of electric heating use. People from Spain belong to **level 0** (7 people) and **level 4** (1 person), not accounting for the 2 cases with electric heating systems and 5 people are included in "**no data**".

4.2.3 Household emissions

For the emissions associated with the household level, many of the answers belong to **level 0** (21 people) while 18 people are in "**no data**" because of the reasons explained before.

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Considering the answers separately for each country, people from Denmark belong to **level 0** (1 person) and **level 3** (1 person), and 6 people are considered as "**no data**" (see explanation before). Most of the Slovenian respondents belong to **level 0** (4 people), followed by **level 4** (1 person), while 3 people are in "**no data**". For the Spanish people, 5 people are considered as "**no data**" while the rest are distributed in **levels 0** (8 people), **1a** (1 person) and **level 4** (1 person).

4.2.4 Transport emissions

Finally, for the passenger transport emissions, we found that 28 people are in **level 0**, which is the most observed level, followed by **level 4** with 14 people. This can be explained because most of them use fuel car as the main transport for their travels.

Analysing the countries separately, we found that in Denmark, 6 people belong to **level 0**, 1 person to **level 2a** and 1 person to **level 4**. In Slovenia, 5 people belong to **level 0** and 3 people to **level 4**. And Spanish respondents belong to **levels 0** (9 people), **3** (1 person) and **4** (5 people).

5. NOTES AND SUGGESTIONS

Reference values for the average energy consumption are based on data from 2015, which has been considered because the main goal is to reduce the consumption by 25% and 16% for household energy and passenger transport energy, respectively, from 2015 values. The reference values are not updated since it is the baseline for comparing how close or far a citizen is to reaching the 2030 goals.

On the contrary, the values for the footprint calculator must be the most recent ones to have a better picture of the performance of individuals. In this regard, we should have the most updated national emission factors for electricity consumption (equation 2). The same happens to the values of the emission factor for electricity generation (equation 4 and Table 6). This implies looking for an open database with reliable and comparable data among EU-MS that in the future can be easy to update. We have decided to use the values from Our World in Data. Emissions factors of fuels are supposed to be constant and inherent to the source, so it would not be necessary for any additional update. On the other hand, emission factors from renewable sources are changing as time goes by, and emission factors of national energy mix are also changing. Thus, it would be recommendable to have the most updated emission factors for such renewable energy production sources. In the case of PV, emissions factor decreases because the emissions in PV come mainly from the energy consumed to produce the solar panels. As the electricity mix of China (where 97% of global production is today) decarbonizes, the emission factor of PV is reduced. This reduction will not affect the panels within our community installation that will be installed in 2023 and hence the emissions associated with the electricity mix that year. The value in Table 6 (0.0305 kgCO2 /kWh) is a good representation of the current status.

The challenge is the lack of public, reliable and open sources ensuring good yearly updates. In this regard, we have only been able to find emission factors for all renewable sources based on year 2015 on reliable open databases (see Table 6 and Table 8). A recent document published by JRC [57] updates only some renewable energy sources to 2022 data. We will update electricity emissions factors to the most updated available data in every year.

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We are also aware that socio-demographic aspects are influencing the final data, despite citizens' behaviour. This is a matter of another task AURORA is performing. An example is the well-known Energy Efficiency Standard in Buildings and how it can easily evaluate the increase/decrease in the household energy consumption of a family regardless of their habits. Aspects like age/activity of the inhabitants are also reported in the literature as a key factor in the final energy consumption. In this regard, AURORA will deal with such factors in an upcoming stage to finally adapt what has been reported in this deliverable in two manners:

- Firstly, we would like to adapt the level of the label in the future mobile app based on some factors which participants could provide information about, such as the energy efficiency level of their house/apartment. That way we will not request more effort from those whose own household is directly less efficient. Changing a house is not a sustainable behavioural change, neither is spending more time at home because one is retired or spending more energy because it is demonstrated that families with kids demand more energy than those where all occupants are adults. So, we are analysing how to relax the levels for such individuals by applying a correction factor to the labelling algorithm according to the data reported by citizens. We propose applying a factor to take into consideration energy efficiency labels of buildings (see section 5.1 below).
- Secondly, we aim at creating a public database where we can evidence such and other propositions with real citizens' data. We would even like to be able to correlate some subjective effects stated in the literature, such as gender or education level in the energy behaviour. This is just possible thanks to a citizen science approach. In return, we know that not only the label must be given to participants. So a holistic app is being developed to engage with citizens in a continuous way and provide them with such external reinforcement requested for a behavioural change process as commented in the introduction.

5.1 Taking consideration building energy efficiency label

As mentioned in the previous section, the building energy efficiency level of housing is one of the social-economic factors that influence the energy consumption at the household level and subsequently their level in the proposed emissions labelling. People are not able to move from their homes to better-insulated ones just because they want to reduce their energy consumption and their CO_2 emissions. For this reason, people living in an E-G rated building are going to benefit from this new calculation approach and people living in buildings with an A-C label are going to be punished. The question here is: why do we want to punish people with a good labelling building? The rationale for doing so is that people need to reduce their household consumption and the emissions associated with that consumption regardless of the energy efficiency label of their houses/apartments. If they live in a more energy efficient building with good energy labels, they are closer to NEAR-ZERO even if their consumption pattern is similar to those who live in less energy-efficient building with a much worse energy label. With this new approach, everyone starts at the same point: at the reference value, by applying a corrective factor from their building label. From that, their energy consumption can be compared independently of the type of building they live in and everyone will have the same opportunities.

Taking Spain for example, the reference value calculated for a specific region corresponds to level D in the building energy efficiency label. The rest of the levels are calculated based on a ratio and the reference values [58] [59]. Quantifying the levels in terms of energy consumption, level A corresponds to a 55% consumption of the reference value, level B means a consumption between 55 and 75%, for level C, 75-90% of the reference consumption, level D, between 90-100% of the consumption, level E limits are the reference value and an increase of 10% in this consumption

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value, level F means a consumption between 110 and 125% of the reference consumption, and finally, level G consumes 125% of the reference value. Level A is also divided into categories more efficient named A+, A++ and A+++, which consume less energy when increasing the "+" in the label level [60]. Considering these percentages, the proposal follows the rules from Table 15 regarding their energy consumption.

Table 15. Percentages of punishment or benefit applied to the building labels

BUILDING LABEL	PERCENTAGE OF PUNISHMENT OR BENEFIT
A	+45%
B	+25%
C	+10%
D	±0%
E	-10%
F	-25%
G	-45%

Note: the reference value is the average energy consumption for each country. The author team plans to conduct further desk research, in order to evaluate whether separate corrective factors needs to be applied for different countries.

Some other socio-economic parameters are also being studied to understand the energy behaviour and to "relax" the label, benefiting those cases such as people working from home (where household electricity and thermal consumption are higher) or considering the age of people (families with children consume more energy than those without children [61], and retired people also consume more energy due to the different thermal comfort temperature [62]).

6. EXTERNAL REVIEW

This document regarding the design and development of the labelling system for citizens' carbon emissions is reviewed by a an international panel of experts. The review panel consists of 12 external review experts, who are nominated by consortium partners and based on our review of literature. Diversity is ensured in bringing the panel: experts come from different countries and regions within and outside EU, with different types of expertise: environmental psychology, energy systems engineering, carbon footprint calculation, etc. We ensured to have researchers, policy makers, and industry practitioners in the panel. Gender diversity is also taken consideration in the process.

In addition to the general review of the methodology introduced in this document, experts are presented with a list of questions (see below). They are expected to give honest and independent answers to these questions.

Table 16 List of questions to external review experts

1	In your opinion, could the labelling system be a useful strategy for driving citizen behavioural change
2	Do you agree with the approach to keep the emissions estimation simple and based on three sectors (household electricity, heating, and transport)?

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3	Do you consider the definition of categories and the numerical values established for them appropriate?
4	Which of the proposed naming schemes for the labels sounds better to you? Do you have any additional suggestions?
5	When considering the implementation of the questionnaire: How many questions are appropriate to ask users when we implement it in the AURORA APP, so we get enough information and users will not be deterred from having to answer too many questions?
6	Do you have any other feedback or suggestions for improving the labelling system?

By July 2022, four reviews were received, and the author team made some initial plans to improve the document. The initial four reviews and our initial responses were included as an appendix in the version (document v1.2) that was submitted to the European Commission in July 2022. By October 2022, eight more reviews were received. Based on these 12 reviews, the author team had gone through several rounds of discussion to address the comment. The comments were divided into 3 categories: (1) suggestions to the report itself; one example of such suggestion is that we should include a general introduction that better describes the objectives; (2) suggestions to the carbon emission calculation methodology, one example is regarding the source of emission factors, another example is the inclusion of an extra category A+ for the labels; (3) suggestions to the development of the future AURORA mobile app, especially with the dissemination and implementation of labels in the app. As another work package takes care of the mobile app development, the suggestions mentioned in (3) were compiled and shared with another working group. Following suggestions in (1) and (2), the author team made a major update to the document to incorporate the feedback (document v1.3-1.9).

This document will be shared with the public on the AURORA website. Needless to say, the document will keep updating after more reviews are received from peer reviewers and/or citizen scientists. An anonymised summary of the expert reviews is enclosed as an appendix to this main document.

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Appendix A: Review of 24 online carbon calculators

- **Available Data**

Name	No docs	Short report (methodology, explanation, etc.)	Report with data sources	Journal publication	API	Open access	Data source access	Offer offsets	No. of questions
Climate Neutral (United Nations)	0	0	1	0	0	0	0	0	28
Environmental Protection Agency (EPA, USA)	0	0	1	0	0	0	0	0	24
Carbon Footprint Ltd (UK)	0	1	0	0	0	0	0	1	42
Carbon Fund (USA)	0	0	0	0	0	0	0	1	24
Carbon Offsets to Alleviate Poverty (COTAP, USA)	0	0	1	0	0	0	0	1	15
Conservation International (USA)	0	1	0	0	0	0	0	1	15
International Student Carbon Footprint Challenge (ISCFC, USA)	0	0	1	0	0	0	0	0	50
My Climate (Switzerland)	0	1	0	0	0	0	0	1	8
World Wide Fund for Nature (WWF, UK)	0	1	1	0	0	0	0	1	24
CarboTax (USA)	0	1	0	0	0	0	0	0	32
Carbon Independent (UK)	0	1	0	0	0	0	0	0	11
Carbonify (Australia)	0	1	0	0	0	0	0	1	10
Climate Care (UK)	1	0	0	0	0	0	0	1	32
Global Footprint Network Calculator (USA)	0	0	1	0	1	0	1	0	18
Henkel (Germany)	0	0	0	0	0	0	0	0	30
Ilmastodieetti (Finland)	0	0	1	0	1	0	0	0	21
Klimatkontot (Sweden)	0	0	0	0	0	0	0	0	22
TerraPass (USA)	0	0	0	0	0	0	0	1	16
Cool Climate Network (Berkley University, USA)	0	0	0	1	1	0	1	0/1	19
Santa Clara University (USA)	0	0	1	0	0	0	0	0	35
CO2Web (Spain, university of Alcala)	0	0	1	1	0	0	0	1	73
NGC (Nos Gestes Climat)	0	0	1	1	0	1	1	0	38
SITRA (Finland)	0	1	0	0	0	0	0	0	27
IMPACT tool (UK)	0	0	1	0	0	0	1	0	_

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- **Sectors considered**

Name	Single country	Household Energy /Separate heating or cooling/ Size adjustment	Transport by car	Public transport	Transport by air	Food	Purchases	Other Fuel	Waste
Climate Neutral (United Nations)	1	1/1/1	1	1	1	1	1	0	1
Environmental Protection Agency (EPA, USA)	0	1/0/0	1	0	0	0	0	1	1
Carbon Footprint Ltd (UK)	1	1/1/1	1	1	1	1	1	1	0
Carbon Fund (USA)	0	1/0/0	0	1	1	0	0	1	0
Carbon Offsets to Alleviate Poverty (COTAP, USA)	0	1/1/0	1	0	1	0	0	0	0
Conservation International (USA)	0	1/0/1	1	0	1	1	0	0	0
International Student Carbon Footprint Challenge (ISCFC, USA)	1	1/1/1	1	1	1	1	1	1	1
My Climate (Switzerland)	0	0/1/1	1	1	1	1	1	0	0
World Wide Fund for Nature (WWF, UK)	1	1/1/1	1	1	1	1	1	1	1
CarboTax (USA)	0	1/0/1	1	1	1	1	1	0	1
Carbon Independent (UK)	0	1/1/1	1	1	1	1	0	1	1
Carbonify (Australia)	0	1/0/1	1	1	1	1	0	1	0
Climate Care (UK)	1	1/0/0	1	1	1	1	0	1	1
Global Footprint Network Calculator (USA)	0	1/0/1	1	1	1	1	1	0	1
Henkel (Germany)	0	1/1/1	1	1	1	1	1	1	0
Ilmastodieetti (Finland)	0	1/1/1	1	1	1	1	1	1	1
Klimatkontot (Sweden)	0	1/1/1	1	0	1	1	1	1	1
TerraPass (USA)	0	1/0/0	1	1	1	0	0	1	0
Cool Climate Network (Berkley University, USA)	0	1/1/1	1	1	1	1	1	1	0
Santa Clara University (USA)	0	1/0/0	1	1	1	1	0	0	1
CO2Web (Spain, university of Alcala)	0	1/0/1	1	1	1	1	1	1	0
NGC (Nos Gestes Climat)	0	1/0/0	1	1	1	1	1	0	0
SITRA (Finland)	1	1/1/1	1	1	1	1	1	1	0
IMPACT tool (UK)	1	1/1/1	1	1	1	1	1	1	1

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Appendix B. Summary of external reviews

Reviewer 1	
1.	a. Yes. This is known from many other commercially available products such as television monitors and refrigerators. Also, an app is a way to push insights and choices for actions. It's a good way to nudge people into thinking of their energy and transport choices and to make them aware of possibilities for emission reductions. b. One thing is, that the labeling system needs to incorporate fairness and transparency. Much of what the document describes in terms of choices of values and calculations should be added to the app as explainers and the documentation for the API and choices needs to be publicly available.
2.	For a start, I think it is a good idea to keep it simple – but in the long run food consumption can be added – right now the EFs for food are too difficult and broad to give a somewhat truthful picture, and scope 3 emissions even harder. But there are already existing calculators including both electronics and food. Have in mind, that this should be incorporated at a later point in time. I think, if left out of the calculation, general tips for cutting emissions should be informed of in the app when it comes to food, scope 3, etc.
3.	a. I think the interval in level 1a is too large (especially for energy consumption). There needs to be gratification for effort. I imagine a citizen could spend some time applying efforts to reduce while having label-1a without advancement. Maybe it would be wise to show the citizen's progress within a label grade? "You are in the top 20% of grade 1a – keep going" or simply make it into two categories? b. If you are comfortable with "next best" a large 1a will probably result in misplaced contempt. c. A smaller interval could also benefit continuous engagement in the app because of more steps needed for the final grade.
4.	a. I think that a well knows naming is best. Titles, animals, and plants can have different cultural and social meanings throughout European countries. It will also require more explaining and thus a higher time requirement from the citizen to understand the labels. b. I think going for the electrical EU labelling is a great idea as the three chosen categories for the calculator are also within the energy domain – this makes it easy and recognizable.
5.	a. This is a difficult question! It's a tradeoff between data acquisition and general granularity of the acquired data. I think 30 questions should be enough. If the questions require the citizen to do something active (like researching your type of heating, for renting people) there should be even less. Think of the importance of the resulting data from a question – is it worth it? b. A suggestion could be, not to acquire all the data in one go. The APP could get basic data at the start and then increase in detail. Let me explain food consumption as a case: the first set of questions could for example be how many days a week you consume fish, red meat, dairy, and chicken. After a couple of days, or maybe a week, the app can send a push message with the opportunity to get more detailed data: how many grams of fish, red meat, dairy, and chicken do you consume a week. Then in another week, it will ask for more details on heat consumption. This will slowly increase the granularity of the data and at the same time ensure continuous engagement in the app without overwhelming the citizen.

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6.	a. Many people are working on CFCs right now – several companies and organizations just in Denmark. I think that your work on finding and comparing the different apps and the literature work surrounding the comparison in this document could be published and could be of deep and valuable interest to many. With some modifications of cause. b. I think it is highly important, that it's shown how people can advance their label. Suggestions for alternate heating sources, different transportation, etc. There could also be a pledge option, where you set a goal – for example, to exchange your heating source within 3 months, etc. – in three months you are then reminded. In general, the document lacks information on how citizens are continuously engaged in the calculations and app. c. I think the document should include a short explanation of how the app should work, not just the calculations, and how the citizen is going to use the app. As the app is the end goal.

Reviewer 2	
1.	In my opinion, the labelling system that has been proposed by the project Aurora has many strong points, but it has also some possible threats that can affect the achievement of its main objective "driving the citizens behavioural". I agree that labelling could be an effective tool in driving behaviour change, especially when it could harness the impacts of both social and personal identity and has the power to bring these issues into people's every day lives. The leverage system, through which it wants to spread from the people, seems based on very strong pillars, people are influenced by their social environment and the fact that someone would start doing this assessment could change also the behaviour of other people too. The most critical point in this work is already treated in the paper, the possible ethical problem deriving from the creation of a rank. Anyway, this problem appears like something that can be overcome by a cautious way of creating this ranking and maybe suggesting it like a personal challenge and not like a competition with other people.
2.	The report properly defines the assumptions and details used for the emissions estimation of the three proposed sectors. However, the approach of analysing the emissions through only those three categories appears like something that doesn't lead to a complete assessment. This let this work possible, because of the problem of the creation of a system that gives us certain information, without the possibility of different scoring due to different points of view of the ones who participate to the project. A more complete analysis could be done with more emissions critical points, like for example the production of waste and the purchases done by the citizen. The implementation of those kind of matters could be the next step of this work to apply in future developments.
3.	The numerical approach considered for the estimation of the emission has been well designed and it appears as effective. In the case of the electricity consumptions, it has to be divided into the number of persons who live in a house and it has to be weighed on the base of the country of analysis, because of the different weather conditions. Subtracting the energy coming from renewable energies would be the best practice because it represents a good behaviour, producing positive externality.

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	For the households warming systems, it can be assessed that analysing the different kind of heating fuels is the best way to understand what the carbon footprint of the process of heating is. The footprint of the transportation sector is more difficult than the other two estimations, but the fact that every aspect has been considered represents a proper methodology to have accurate results. Anyway, for this last calculation it seems, like already considered in the paper, that it would be a bit difficult for the citizens to analyse every movement and kinds of consumptions, especially for the public transport moving.
4.	I think that the best of that 3 name ideas is the first one, because the numbers would be too impersonal and that would lead to a bad relapse on the way people feel about this project (it is important to see the personal impact, people would probably like to feel fulfilled by the results obtained). The plant idea could be another good option, but it could be more confusing (the growth of the plant maybe misunderstood).
5.	The best practice in that matter could be the creation of a first questionnaire, asking a few questions, increasing the will of the person who will answer to deepen their personal carbon footprint. It could be schematized in a “first step” asking only 10-15 answers well structured and simple to answer and a “second step to know better who you are”, made of many questions, up to 100, with which it is possible to conduct a complete analysis.
6.	The labelling would be a really good way to increase self-consciousness of people on the way they hurt the planet with their actions, anyway the possibility of affecting their behaviour would be complete in a methodology including questions about other people behaviours. The diet, for example, would be another critical point to analyse, maybe also increasing the interest of the people in the questionnaire. The use of social media platforms could be used to easier answer the questionnaire or integrate it. I agree to keep emission factors from renewable energy production referred to 2015, if they are the last available public, open and reliable data.

Reviewer 3	
1.	yes. Assuming that the purpose of the label is to change behaviour rather than get to a precise carbon figure (which anyway sounds like it would be difficult, given that other calculators give such different results), then detail isn’t that important. Simplicity is, as is advice about what people could do to reduce their energy use or carbon emissions.
2.	yes, though another approach would be to use an existing calculator/app, or even trial several of them. It would be good to know why the work is limited to electricity, heating and transport rather than also including other topics (e.g. food), as is done by some other carbon calculators.
3.	no, please see my letter. I don’t think that the current ‘almost net zero’ category should have that name, and I think that the label should be skewed towards the lower energy ranges. --It’s also not clear why your label would have five levels (with 1a/1b being green and 2a/2b being yellow), rather than seven labels as in the standard EU energy labels. I think that it would help to incentivise people to have seven levels and be able, e.g. to go from 2b to 2a, from 1b to 1a.

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	--I really don't like the term 'near zero' when people's energy use/CO2 emissions (Table 1) isn't even close to zero. 'Near zero' really should be near zero, e.g. Passivhaus standard, minimal energy use and that provided via PV, mostly walk/cycle. I would be tempted to have fewer categories under your level 2b and more above it. (e.g. for Spain the worst level could be >983 or 936, and then more categories above that, ending in near-zero = approx. 100).
4.	I would definitely go with alphabet, A-G, rather than emojis, animals, etc, as A-G labels are well understood and commonly used. --I strongly recommend that your calculator should use the same colours as those used in standard EU energy labels: dark green is most efficient and light green less efficient. At the moment, Table 1 has light green at the top and dark green further down.
5.	This goes with question 2 about simplicity. I feel that 10-20 is probably plenty.
6.	-- It would be very helpful for Deliverable 1.1 to have an introductory, objective-setting section which includes the bullet points in this 'general approach' section. -- Page 17 of Deliverable 1.1 states that "the final goal of AURORA is knowing how well citizens are performing to reach Green Deal goals". Is that correct? Or is it to reduce citizens' energy consumption (or carbon emissions) to Green Deal levels? Or to assess the effectiveness of carbon calculators? -- I have only looked at the current UK energy use figures 2020-22, but these seem quite different from those in Tables 3 and 4 of Deliverable 1.1: see https://www.statista.com/statistics/517845/average-electricity-consumption-uk/ and, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1018725/efus-Household-Energy-Consumption-Affordability.pdf Do you know how reliable Our World in Data (p.24) is? Would it be better to use the five countries' government figures instead? -- At various points (e.g. top of p.10) your report suggests that reduced energy use is a goal in its own right, not just a way of reducing carbon emissions. I agree that this is a good approach, and feel that this could be stressed more clearly, with reference to the energy hierarchy -- I have not been able to find the Green Deal goal that your report refers to, of 25% reduction in electricity and heating and 16% reduction in transport carbon consumption. Please could your report more clearly refer to the source of this goal? -- It would also be good to know why, given the wealth of existing carbon calculators, your research involves developing a new one rather than rolling out an existing one. What is the 'value added' of the new calculator?

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	-- … and how does all of this fit with crowd-funding 1MW of photovoltaics? Especially given that the energy hierarchy focuses on reduced use rather than provision of renewables? I think that all of this needs to be explained up front. -- It seems reasonable to peg the levels to country averages (Table 1), although this masks the fact that some countries (e.g. UK) use a lot more energy per person than other countries (e.g. Portugal). It may be worthwhile letting people choose, in the calculator, what they want to use as their basis of comparison: the EU average or the country average, with an explanation of the discrepancy. -- It's not clear to me why heating technique should be an input (p.18) since the important point – the energy use - is dealt with via questions about energy used. -- Also (I don't know the answer to this one), if I have a renewable heating source, would I know how much energy it produces? -- I also think that it is expecting too much for people to know the fuel source of their bus (p.21), especially since they can't alter their own behaviour in response.

Reviewer 4	
1.	The proposed labeling structure is set up as a five levels grade system, which follows the already established energy efficiency labels. The approach can be considered as appropriate, since the "level grading system" has proven to be not only more esthetic, but also clearer to the end-user. Such labeling system can be a useful strategy for driving citizen's behavioral change – as proposed, it should attract not only the group of people that are already familiar with the topic and try to be proactive about it, but also the group that at the moment do not consider making any steps towards reducing their carbon footprint.
2.	Since the CDC is meant for the use of the citizens, the selected group of observed sectors (households and transport) can be considered as appropriate. By changing the behavior the citizen can have major influence only on those sector, this is why the selection is suitable.
3.	Taking county-specifics information into account is essential in order to present credible information and results to the end-user. A more novel approach here is the 2-step approach to the information reveal. At first, only label will be seen and, in the case, if the user would want further data, the later will be provided interactively through the calculator. Presenting the results in this manner could be a big advantage of the calculator and is therefore, a novel way how to present complicated data in a clear way.

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	What is not exactly clear is how the values for energy demand were calculated. A shortcoming of the proposed values is that the grading system is based on aggregated values. A households that lives in a big house, but it's energy efficiency is very low, will easily reach high levels on your proposed scoring systems. For instance, 5500 kWh in a 150 m2 presents a 37 kWh/m2 specific heat demand, but in a 250 m2 house this results in a 22 kWh/m2 specific heat demand. The difference is obvious. I would propose asking the user about heated floor area of the house and build the system based on specific values of the chosen parameter. Furthermore, the terminology should also be double-checked. Energy demand usually in literature present a value of energy need for heating. This parameter reflects the condition of the energy efficiency of the thermal envelope (façade, windows, roof,..) and is not taking into account technical systems at all. The final app will probably ask the user to input their overall energy consumption, the amount of energy they actually paid for. This parameter can be stated best as energy consumption.
4.	Regarding the proposed naming system the consortium clearly devoted many thoughts into the matter which is going to reflect on the final product. The combination of alphabet letters with traffic light coloring and positive adjectives can probably result as the most efficient way of the result presentation. It follow the already established "energy efficiency labeling system" and it upgrades/connects it with a climate-related adjective.
5.	In the calculator review section it was found out, that calculators with long and detailed questions are not very popular. It might be better to have simple questions first to draw in users, and then have an extra part for more detailed questions for interested users. In the area of energy use in building calculation, H2020 REPLACE project present the "heating system replacement calculator2" that offers an easy, interactive way how to make complicate calculations – simple and present results in such manner as well. The authors are welcome to check the calculator and explore possible use of it within carbon footprint calculator. The AURORA app will have to subject the end-user to some question in order to properly calculate their CF. By doing that, the team has to be careful with the selection of question in order not ask too many question. Up to 10 question should be seen as a limit in order to get the quick evaluation of CF. Regarding the building sector, questions such as: heated floor area, heating system, energy consumption for heating and electricity are practically enough. By using other simplifications, the CF can be then quickly calculated.
6.	The selection of natural gas as the most commonly used energy carrier for heating in households can be stated as unfounded. Indeed, there are many condensing gas boilers installed in the 5 observed countries, but there's no justification to support this decision. The source (Koffi B. et al, 2017) does not tackle the topic of most commonly used heating systems in households, but it only gives the emission factor of 0.202 kg CO_2/kWh. For example, in Slovenia the most commonly used heating system in households are biomass boilers, next up are heating pumps and general application of natural gas as the most commonly used energy carrier is wrong. Furthermore, it probably send the wrong message to the general public in light of promotion of technologies that exploit renewable energy sources as a solution in tackling climate changes. Should the calculation methodology lean in this way of calculation, the authors should devote more time into average CO_2 emissions factor depending on actual shares of used energy carriers in respective countries.

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	Different heating technologies, e.g. biomass boiler, condensing gas boiler, heat pump, etc. are considered as a technology and not as heating techniques. The terminology should be double-checked. The values of emission factors should be double-checked. Table 3 present the factor of 0.256 kg CO2/kWh for Slovenia in 2015, but this clearly differs from the actual condition. E.g. the factor in 2015 was 0.384 and in 2020 is 0.3261. Both values clearly differentiate from the proposed value. Furthermore, the calculator should use more “up to date” values. The calculation methodology for carbon footprint calculation of electricity consumption, thermal energy consumption, and transport is clear and understandable. It follows the basic calculation principle. The most important question for the authors would be regarding the input data. How are the authors planning to present the question to the end-user in order he/she will input the supposed values? It needs to be pointed out there are many inconsistencies regarding the interpretation of what is final energy, energy consumption, energy demand, energy use, need for heating etc. The final AURORA tool should present the questions to the end-user in clear and understandable manner. What is clear that the issue of using heat pumps for heating has not been addressed yet. • It’s not possible to ask the end user for their heating demand. Strictly speaking, the values presents an energy need for heating and is a result of an energy efficiency building calculation without taking into account technical system at all. One possible simplification could be made, if the end-user would input their energy consumption (in either Sm3, liters, …) and the calculator would calculate energy demand in kWh by multiplying energy consumption with net caloric value. • If the user is using heat pump for heating, it’s not possible to distinguish without proper analysis between energy demand, overall energy consumption and separately for heating. This means the calculations as described in 3.2.1 and 3.2.2 would show inaccurate results. • The problem could be tackled with 2-steps: i) make assumptions on what share of the overall energy consumption can be assigned to the heating systems and to the other use, ii) ask the user about their heating systems. By using the efficiency of system, you could calculate energy use for heating One of the biggest challenges of CFCs is getting people to come back to the calculator frequently and reconfigure their daily practices to reach a sustainable level of footprint. It has been suggested that goal setting and continuous feedback can help engage users in the long term. The deliverable does not propose any way on how it is planned to check the influence of the daily practices. One example of such app can be seen on the Financial times’ Climate game (https://ig.ft.com/climate-game/), where you are able to see the overall impact based on the decision you are making.

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Reviewer 5	
1.	Yes, generally I think that a citizen labelling system could stimulate behaviour change among citizens – depending on how it is implemented. What I consider crucial is that it is motivating people, no matter where they currently are in the transformation process (i.e. no matter on which level of the label they currently are). This can be achieved by choosing positive, encouraging adjectives for the different categories of citizens (I think you made the right choices for the adjectives). In addition, it could be achieved if citizens of each category are assigned different roles and (exclusive) features in the app, such that there is a benefit of moving up the ladder (e.g. becoming an “Ambassador” opens up new functionalities in the app). It is probably a little difficult to come up with enough interesting features to create enough incentives to move up the ladder, but maybe the consortium could explore the options in a brainstorming session. It also depends on how interactive you plan to make the app. I believe that the app can be more successful the more interactive features it has, to make use of goal setting, social comparison, social learning etc. Yet some of these features might raise ethical issues, as you also mention in the report, if they require public display of the label status of people.
2.	Clearly, the simpler, the easier to calculate. On the other hand, the fewer activities and behaviours are included in the calculator, the fewer possibilities for citizens to make changes and improve their CO2 footprint, and to see progress on their gradual development from “Foundation” to “Ambassador”. I think from the behaviour change and motivation point of view, a richer calculator could be helpful. But I see the trade-off between a richer calculator and the amount of calculation effort and the amount of questions that would have to be included in the app. In my view it is important to include enough activities and behaviours in the footprint calculator that can be adjusted on a daily basis, as only then people can be engaged through the app continuously. If the activities underlying the footprint calculator are one-time decisions, like investing in a solar panel or a clean heating system, buying an electric car or similar activities, the app users will not have many opportunities to improve and make changes to their citizen label. But including more activities and behaviours, and also those that can be changed on a daily basis, will make the calculation of the energy use and footprint more complex. I think you will have to find a compromise between complexity of the calculation and variety of activities / behaviours that enter your calculator.
3.	I find the categories appropriate. As mentioned under 2.), I think it will be essential that you allow many different activities and behaviours to determine the amount of energy used/emissions created in the three main categories. Regarding the numerical values, it is difficult for me to judge whether they are appropriate. I am an economist and not an engineer. But the way you described your approach, using the average values of 2015 as a reference, and making the thresholds country-specific, all seem to be reasonable choices to me.
4.	I find the positive adjectives most attractive, as they signal to the users of the app a certain role that they take on in the transformation process and in the community. As mentioned in my general comments, such a naming scheme could open up opportunities for social interaction between citizens (app users), for example, in that “Pioneers” reach out to “Leaders” or “Ambassadors” to learn from their activities and experiences (e.g. how to install a heat pump or solar panels).

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	Regarding the adjectives, I find them generally well chosen; except for the first two categories: “Foundation” as it is not representing a person like the other adjectives, and “Pioneer” as it suggests a higher level of sustainability than a person on the second level would probably have reached. A suggestion for alternative adjectives for the first two categories could be: Explorer, Mover or Progressor, Transformer, Leader, Ambassador
5.	This question should probably be answered after you have defined the target group for your app. Citizens with little interest in sustainability can probably only be motivated to use the app if the amount of questions is limited. Citizens with a high interest in sustainability and a high pre-existing motivation to improve their carbon footprint are more likely to answer a longer list of questions. For the less motivated people, maybe 10 questions are enough; for the more motivated people, probably up to 30 questions would be fine. If the app should reach less and more motivated citizens at the same time, maybe you could also consider having two different modes of using the app, like simple mode (10 questions) and expert mode (30 questions), and the users get to choose what mode they are ready for. Of course they would have to be informed that the simple mode is based on a simplified calculation and can only lead to a rough classification, whereas the expert mode is more detailed and thereby leads to a more refined classification. Not sure whether this is technically feasible, but it could be an idea how to deal with citizens’ different expectations and motivations.
6.	As I mentioned in my general comment above, what I missed was a more detailed description how the label would be displayed, how frequently app users would enter new information into the app, and how frequently the label would be re-calculated to demonstrate progress on the ladder to a near zero lifestyle. I also missed information about the interactions between app users, how the label information is used to connect people, help them learn from each other, and maybe also whether entire neighbourhoods or communities could learn about how frequently the five label categories are represented in their community. Such information could be used by municipalities, e.g. to encourage citizens to increase the share of “Transformers”, “Leaders” and “Ambassadors” in the community, thereby using social dynamics. I think one could come up with many possible features but my impression is that this aspect of the development of the label and the app has received little attention so far, while more emphasis was placed on the development of the calculator tool. Yet I think the effectiveness of the label and the app for behaviour change will crucially rely on the features the app offers to its users. For the further development, I recommend focusing on this aspect in particular. Overall, I find the idea of a citizen labelling system to stimulate behaviour change very interesting and I congratulate the consortium for this innovative idea. What did not become fully clear from reading your report is how the label would be presented to the citizens. Would it be shown to the citizens in the app, after filling in the questionnaire? (Probably… but beyond that the report remains rather vague.) Would it be posted on social media, such that it is also visible to others? Could people see in the app what labels other citizens from within their community currently hold? Could they see whether any “Ambassadors” live in their neighbourhood, and maybe talk to them an learn from them? In short: how would the label be displayed and what features would the app offer for people to not only know their own label but to also get in touch with other citizens that are either at the same stage as they are, to exchange experiences, or at a “higher stage”, to learn from them? I would find it very useful if the report also includes a section where it is

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	specified how the label would be displayed and what features app users would have once they “received” their label. How frequently would they be invited to update their information to track the behavioural changes they implement (and to move up to a higher label)? All these practicalities remain rather vague in the report, but they might have a strong influence on the effectiveness of the label in stimulating (continued) behavioural change among the users of the app. This part is missing in the report and should be added, to make the report complete (unless this is done in another deliverable/report that was not part of the review).

Reviewer 6	
1.	This depends. The current scope of work is not detailed enough to gauge if this could really be an effective means to drive behavior change. There are three reasons for this: • The implementation plan should be further elaborated upon. For example, the labeling score seems to be based on self-reported data from the users. This type of activity can be useful for a single evaluation/learning activity, but it might not help drive behavior change over time. To do this, suggestions include connecting the app with electricity meters at the household level to show actual energy use with prompts for energy reduction. If this is technically not feasible, users should be given monthly to add electricity bill data, daily prompts to add transport data, seasonal prompts about heating/cooling systems. For further literature on implementation, I suggest looking at the work by D. McKenzie-Mohr, Fostering sustainable behavior: An introduction to community based social marketing. New society publishers, 2011. • The incentives for the users should be more clear or more convincing. From my experience in creating a user-behavior app ‘Our Energy’, marketing is everything. To get people to use the app, they should also feel like they are gaining something from the app beyond a label and good-will, especially for those who have limited interest in energy efficiency. For example, with our app we found users by asking people if they would like to ‘try solar’, something that is not possible without already investing in the system. This was therefore an experience for them to see how they can shift their current energy behavior to electricity produced by a local PV system through real-time PV production simulation and self-reported data of appliance usage at the household level. Even at this, it is a 2-week experience which was already subject to participation fatigue. • For long term usage, you should try to better predict and understand what people want from such a labeling system. Better understanding their needs will help to design the interface, prompts, and overall concept to drive behavior change.
2.	The short answer is yes, it is best to focus attention on energy systems rather than including all possible ways to reduce emissions through food choice, consumer product choice, etc. The broader the label becomes the less useful it becomes at targeting energy behavior change. As you already pointed out, it is very challenging to collect sufficient information about emissions from all consumer products, foods, etc. and further estimates then dilute the value for what could be provided for the three energy sectors that have been identified.
3.	It is clear that the project team has dedicated a large amount of time to establish the categories and the numerical values for the labeling system, particularly to meet the local context for the selected countries. What is missing is a baselining period for which you learn about the behavior of the users which I imagine greatly depends on the socio-economic context and background. It is common that more affluent people will have much higher

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	CO2 footprints than middle-income and lower-income households. The label should avoid excluding upper income households who have a great potential for energy reduction.
4.	From the three proposed, I personally like the positive adjectives best. However, I might also suggest conducting a feedback round from a few select communities in the case study countries to learn what would be better for them. This type of participatory engagement would be useful to also learn about the local contexts to improve upon the labeling scheme, feedback information, and incentives instead of taking averages for each country.
5.	I don't think there is a magic number of questions, but for participant studies the rule of thumb is to only ask questions that are relevant to study or proposed objectives. Yes, less is more, but if you need to ask additional questions to complete the information required for the study, then it is ok to ask additional questions that are clearly formulated and support the project. The easier the questionnaire the more likely people will fill it out, especially on a repeated basis.
6.	The current report does not discuss the implementation plan as pointed out in question 1. This could be improved upon to strengthen the actual chances for sustained behavior change for carbon emissions reduction. The beginning of the document briefly mentions the importance of community and social norms/social identity, but this is not further elaborated upon. I do agree that community is very important to drive pro-environmental behavior particularly around jointly owned renewable energy systems (but I am biased from my work here), but I do not see how the labeling system, or the implementation takes the community or local context into account. This could be strengthened. What are the benefits to the users besides knowing more about CO2 their footprint/label? Apps require a lot of time from the user, particularly if they require self-reported data as opposed to measured data. People need some type of economic or unique experiential benefit in addition to this information otherwise you risk the chance of limited user engagement. Is there a possibility to connect metered data of electricity or heating for real-time feedback? Various studies show that behavior change needs to have clear information and feedback for specific actionable behavior at the moment the behavior needs to be changed. For example, see the study: Verena Tiefenbeck, Anselma Wörner, Samuel Schöb, Elgar Fleisch and Thorsten Staake, Real-time feedback promotes energy conservation in the absence of volunteer selection bias and monetary incentives, Nature Energy, https://doi.org/10.1038/s41560-018-0282-1. • Not only does measured data allow for people to have real-time information for behavior change, but it also holds them accountable. I would also recommend looking at this study which shows the limitation to self-reported data and people's perception of their own energy conservation behavior: Devon Wemyss, Francesca Cellina, Evelyn Lobsiger-Kägi, Vanessa de Luca, Roberta Castri, Does it last? Long-term impacts of an app-based behavior change intervention on household electricity savings in Switzerland, Energy Research & Social Science, https://doi.org/10.1016/j.erss.2018.08.018

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Reviewer 7	
1.	Overall, the labelling system is well thought-through and backed by significant previous research on behaviour science and findings therefrom. The estimation however seems to be based on household data (e.g., energy and heating consumption is for whole house where several people maybe most likely co-living) rather than individual data. Hence the label as a 'Citizen' system can be a bit misleading.Labelling an individual also opens up risks of societal stigma and typecasting. This can be 'de-risked' to a large extent by using the 'household' label instead. It also does not consider that as an individual, the person would be able to take different environmentally-friendly actions at different places such as in their school or work location. The proposed label does not reward the individual for such actions at other significant locations where they spend their day. On the other hand, actions such as installing rooftop solar panels and buying energy efficient equipment impact the whole household and does not really take into account the action of each individual in the household.Also, as many individuals tend to have a stronger belonging to the household, the use of the term 'Household' (or equivalent) might be better. Secondly, as there will be different levels and stages of an individual's life journey (age, type of work, personal goals, physical/mental health, etc.) the household score will help balance it out and provide a robust 'reminder/nudge' mechanism for household members to adopt near zero emission behaviour. It also opens up economic opportunities, such as commanding a rental premium or value appreciation of the property which benefits the household and its members directly as financial incentive. If my understanding is correct, the main goal as stated in the document is 'to reduce the energy demand by 25% and 16% for household energy demand and passenger transport energy demand, respectively, from 2015 values'. Hence it is strongly recommended to consider naming the labelling scheme as the 'Near Zero-Emission Household' label.
2.	The approach of prioritizing the simplicity of the calculator while capturing the most important indicator, is a good approach to start with. However. I observed that the team struggles on calculating the transport related carbon emissions. The reference of transport data as calculated in Table-5 is too aggregate. Especially calculating the transport energy consumption per capita by dividing the total country high-level number by the number of inhabitants, seems to much of a 'gross' approach that assumes every individual travels equally and has similar access to transport option. Also, the calculation of transport carbon emissions, needs the user to input their distance travelled and, in my opininon, not many people keep a track of distance they travelled daily/weekly/monthly. Hence this will make the user experience of using the calculator and the app as negative or not-favourable. My recommendation is to either drop the transport aspect altogether or to modify the calculations based on transport options chosen by household. E.g., As a very simple calculation approach, households could be penalized for every car they own. Distinction could be made for penalty-level of fossil fuel, hybrid, or electric car. It's a known fact that public transportation is much more carbon efficient than private cars. Other approach could be to ask users to state what % of their travel was made by public transportation or by cars or bicycle, etc. Again, the overall goal should be kept in mind when deciding on this calculation ('to reduce the energy demand by 25% and 16% for household energy demand and passenger transport energy demand, respectively, from 2015 values'). Unless, the transport sector calculation mechanism is revamped, my recommendation would be to drop the transportation/mobility aspect in the label and make the project laser focussed on household energy (electricity and heating) consumption goal support.

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	The more the calculation complications, the more the project team will be busy in the implementation phase later to just answer user queries and keep users satisfied and motivated to use the app (this may hamper research outcomes)
3.	The proposal to have a set of thresholds defining the labels that are different for every country makes sense and in will also address cultural norms and language (e.g., choice of words) for the app.Please see above comments on Q2 for the transportation/mobility section.
4.	The 'Alphabet letters with traffic light colouring' naming scheme sounds better as it will be more universal and avoid translation into different languages when implemented in different cities. The other two naming system will have to be more careful as it has to consider and be sensitive to cultural and language norms in each country. A slight modification suggested to avoid using too many alphabets is to follow something like below options:• A1, A2, B, C1, C2• A+, A, B, C, D• NZ, A, B, C, D (creating a clear distinction of net-zero (NZ))
5.	In my opinion, the questions could be layered in a way that only a few questions can be asked upfront, and more questions could be asked further based on user inputs. E.g., in first layer of questions for electricity, only ask for electricity bill data and a Yes/no question on whether they have installed any solar PV or renewable energy. In the second layer, if answer to the second question is yes, then open up more questions about solar PV. Preferably, there will be also guidelines or illustrative guidance along with the questions on where the users can find the entry values to be entered in the app.
6.	Carbon footprint calculation for the electricity consumption needs to be reviewed more carefully with regards to rooftop solar PV installation on household. Depending on the electricity metering policy in the country (i.e., net metering or gross metering) the electricity bill may or may not show the effect of rooftop green energy production. In case of net-metering the total bill will show electricity bill that has already deducted the solar PV generation. In that case, based on the currently proposed method, the user will get a double benefit for Solar PV in carbon footprint calculation, one from the reduced electricity consumption (due to self-generation) and other from much lower Solar PV emission factor of generated electricity.More explanation on the above:Net-metering: It calculates the difference of energy exported from your solar power system and import from the grid. You either pay for the difference in units or get paid by the utility company for extra units at the end of the billing cycle (based on the policy directive).Gross Metering: Gross Metering requires an extra electricity meter to measure the outflow of electricity from your solar power system to the grid. As a result, the prices for electricity consumption and electricity generation vary. The regular meter records the total amount of electricity consumed by you. You will be paid a pre-determined feed-in tariff (FiT) for the electricity exported to the grid from your solar power system. Further reference: https://sam.nrel.gov/forum/forum-general/3697-net-billing-for-spain.html

Reviewer 8
Overall, the report is very informative and gives a good overview about the project work and findings. However, one of my main questions is, whether or not a label is really necessary or whether it should rather be a " self assessment" to determine if the personal footprint is in line or not with the needed climate actions. If so, a regular adaptation would be needed.

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here are a few issues, which you could address to give the report more weight. 1) Table 1 : Given the fact that the Green deal scenarios are still counting on large scale, not yet ready technologies to reach climate neutrality by 2050, my suggestion is to find another wording for the "Near-Zero" level, as it is scientifically not proven that the scenarios will be able to deliver. 2) Table 1: For Portugal and Spain there are significant differences in the label values, especially for electricity consumption and heating consumption. This should be better explained. The question also arises if a national average for large countries like Spain are meaningful, given the climatic differences in the country. 3) Table1: it is not clear where the difference in the mobility values between Denmark and Portugal come from. Both countries have similar distances. 4) You explained the reasoning for 2015 data as a baseline. However, like EE labels the proposed label should be dynamic as well. A class A+++ fridge from pre 2021 is now only class C. Minor Comments: 1) Page 4: Ref Tajfel et al is missing 2) In the same paragraph: what about local installers, who can have an important influence. 3) Page 5, second paragraph: what about rebound effects, i.e. old appliances are not retired but used as a second one 4) Page 9 figure2: please add the countries to the graphs 5) Page 9 paragraph below figure 2: If you have a background about the topic, the message can be understood, however a better description, especially about the national energy mix would be of advantage. 6) Table 3, 4: What are the references for JRC and World in Data in the reference list? 7) Table6: a common CO_2 value for all countries is not correct, because of the radiation difference between the countries. 8) PV CO_2 values from a 2014 are rather outdated as the database for this publication was probably 2010. 9) Table 7: it looks like that the CO_2 value for natural gas is without methane and upstream emissions. For oil transport and upstream emissions are likely not considered as well. 10) Table 8: Why are heat pumps not mentioned? What kind of geothermal applications do you refer to?

Reviewer 9	
1.	In theory, labels can be a useful strategy to communicate information about performance, and in this way act as an aid to behaviour change. The examples given at the outset of the report are good instances where labels are a logical choice. For example, in the context of fridges, these household appliances are easily measured for energy consumption in test conditions using standardised operation, and their role does not change over time and so a single fixed label at the point of purchase is appropriate. Whilst the way in which the purchaser of the appliance behaves will ultimately dictate how

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	much energy the fridge uses in practice, the tested kWh annual value and subsequent display as a label give consumers reasonable confidence and transparency about what is being purchased. The argument then moves to discussing identities (both personal and group) and how these might impact behaviour. Again, it seems clear that there would be a relationship here. However, it then appears as though a leap is being made that implies it is therefore a worthwhile exercise to apply labels (even if voluntary) to citizens and that this may therefore modify or improve their behaviour with regard to energy consumption and climate impact (penultimate paragraph of page 5). This does not really seem to be properly substantiated (and in addition to this the point is made that the label should be designed to be meaningful and relevant, which should not need saying i.e., it is clear a meaningless or irrelevant label will not find a use). There is a huge difference between devising a method for, and applying a label to a relatively straightforward/predictable product as opposed to that of a citizen. In terms of applying performance standards to citizens, the closest thing available is carbon footprinting (either personal or household). This is covered in Section 3 which includes a search and simple appraisal of some of the more commonly used calculators. The discussion of these calculators (termed CFCs here) would have benefited from being included from the outset here. A label cannot be produced without basing the final rankings on some calculation method, and this is effectively what a CFC is. So in some ways the issue up front should be whether a labelling schema is needed to be applied to current methods of using CFCs. There needs to be a more clarity about whether AURORA seeks to address some of the current shortcomings of CFCs (e.g. variability, lack of standardisation or transparency), or whether the issue is more about how best to communicate the outputs of these methods to best drive behaviour change (which could therefore mean focussing on applying labelling or communication methods to existing CFCs). The appraisal in Section 3, and this reviewer's own professional experience here, can confirm that there are huge and variable challenges associated with getting accurate data from calculation methods that are both time-based/dynamic and achieving a level of granularity that can help drive continual change. There is a distinction between a simple high-level calculator e.g. the well-used WWF tool that can help you get a snapshot of your baseline footprint and point you where to focus your efforts, and some tool that continually tracks performance. It feels like AURORA targets the latter of these, though this is going to be really hard to do, and would also imply a dynamically changing label rating. It is also worth stating that there are already tools out there e.g. Giki Zero that seek to address what is being sought through this project, available on the market. In summary, it may be that citizen labelling has a place, but this cannot be properly considered unless the underpinning calculation methodology is comprehensive and credible, and it seems like currently we are a long way from that. In the meantime, reporting tCO2e/person or household and being transparent about what this covers is likely to be more appropriate.
2.	No. The use of three sectors is far too narrow. The review of alternative CFCs already shows that things like food and products are quite routinely being included within these tools. They are also areas where there is a significant opportunity for behaviour change. Their lack of inclusion risks seriously undermining the credibility and take-up of what is being proposed here. Granted, there are not insignificant data issues around including these categories, but even with this it would still be preferable to have a complete if less accurate picture.

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	The labelling also proposes focus on both energy and carbon. It is true that there are benefits to reducing energy in the face of the ultimate goal of decarbonisation, and that there are EU targets for demand reduction. However, ultimately the aim of AURORA is decarbonisation and the label's focus should be on carbon. By all means consider communicating energy in some way, but having two labels and gradings will likely be a source of confusion to users. For an example, the Energy Performance of Buildings Directive (EPBD) EU legislation resulted in the uptake of Display Energy Certificates for public buildings in the UK (and across the EU). These have an A-G coloured rating based on carbon similar to what is proposed here, and there are additional energy metrics displayed smaller/in a secondary way elsewhere on the certificate. Even for the "sectors" chosen, you could argue that there is ambiguity for the end user. A typical person might be interested in the emissions from their home, but this would be the sum total of all fuel and power used in the home (i.e. Scope 1 combusted fuels like gas or oil) and electricity. Sometimes the fuel is used for heating, but it can also be used for hot water and cooking. Electricity similarly could sometimes also be used for "heat", and will be more going forward as decarbonisation policies will result in the increased use of heat pumps. Electricity use will also include other thermal conditioning, for example cooling. So it does not really follow that separate output categories and reporting thresholds may be needed for each of "heat" and electricity (though clearly a breakdown of all of this would be needed as inputs to the calculations). Similarly, for transport it seems that this covers all personal transport but users might want to distinguish between things like personal transport (e.g. in their cars), public transport, flights (e.g. for holidays), travel for work (either commuting, or during work and what is in scope or not), and there are also transport impact of their behaviour e.g. upstream transport of purchased products (does not sound like these are proposed to be included). So it feels more thought and perhaps user testing might be needed. The other comment to make about very high-level outputs and sectors is that keeping things very simple, whilst good in some ways (easy to calculate and requires less inputs) also seriously risks missing out all the detail that is highly relevant to enabling the sort of behaviour change that is being targeted here.
3.	The targets: No, the classification of these targets and thresholds does not feel right at the moment. There are two things that could be considered in terms of defining these, namely performance relative to targets (e.g. EU 25% energy reduction targets), or performance relative to peers/the wider population. It feels like the thresholds have been somewhat arbitrarily set relative to the former. It may make more sense from a behaviour change point of view to set the thresholds relative to everything else out there e.g. for an A to G rating, the D/E boundary becomes "median" and the A rating the top few % (or whatever). It feels like assessment of performance and distribution and standard deviations etc. should at the very least have been investigated here, rather than simply going with some 25% reduction. It is noted that this population approach is the one that has generally been applied in the buildings sector, and also to distinguish between appliances (hence the need to re-baseline everything as all were getting > A, A+ etc as time has passed). There are also some very real problems with the current thresholds showing "near-zero" carbon emissions as well over 2 tCO_2 and actually a lot closer to a Level 4 rating than zero. It seems really unlikely that this will be taken seriously by people.

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	There are also issues with having separate thresholds for different member states. Doing this all for different countries has significant logistical problems (which perhaps explains why most current CFCs are single nation facing), but ultimately if the aim is decarbonisation and “one planet” living, then the answer has to be the same for all countries in order to be equitable. No doubt this will reveal (if extended globally) that African countries are in fact the “best performing” here. But this tool should not seek to shy away from exposing some of the differences in carbon emissions between people living in member states. The headline and graphic could be based on comparison to EU averages or targets, and perhaps (as with energy) there could be secondary information that relays how well a person is doing compared to other people either across the EU or in their own country (e.g. you are in the top 50% for the EU and the top 25% for your country). The threshold values also appear to imply these are annual figures. The calculation inputs seem to suggest that these can be based on some user defined period of time though there are some dangers to this (see below). But in addition to this, the annual nature of this implies the need for annual repetitions of the data input and thresholds, and this has real problem. The authors themselves have already quoted papers that suggest getting people to stay engaged, recalculate emissions from calculators etc. is highly challenging. It is worth at this stage also stating that Table 4 is overly simplistic in that gas is not the only heating fuel and in some places oil and coal might be significant. Similarly, the data in Table 5 in terms of kWh used in transport is typically not available, and energy is not a well-used metric to describe consumption here (much more likely to be distance, fuel used, emissions etc). Certainly at an individual level, no one would know their kWh of transport energy used, and if looking to create bottom up calculators for use here, it would be better to focus on carbon where there is more data (e.g. vehicle manufacturers already test and state gCO_2/km). Calculations: The proposed workings and formulae underpinning the tool are given later in the report. In general, these involve applying the well-established activity x emission factor equation in various contexts. As a high-level point, there is a real danger that in keeping things so simple and narrowly focussed, you don’t actually capture any of the complexity or behaviour associated with personal carbon impact. Without detailed inputs, you won’t get rich disaggregated outputs. This is compounded when thinking about the problem over time. Missing out consumption from goods (including food) and services is also very problematic, even if there are challenges in obtaining reliable activity data and emission factors. In general, the approach is very simple, and really too simple in order to get meaningful outputs. That said, the electricity footprint section and PV offset seems convoluted for a typical user and it may be possible to just ask for household generated kWh of electricity rather than a rated power of a system, which would then require calculations and all sorts of assumptions to be made. The thermal section is at present needs more work. The period of fuel data has to be related to time of year and temperature e.g. degree-day adjustment otherwise it will not be valid. Clearly submitting gas use for a period in the summer and then somehow applying that to annual performance is going to completely understate the real impact. There are similar issues on electricity and cooling, especially for Southern Europe (and Northern going forward

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	with increased heat pump penetration). The inclusion of temperature adjustment needs serious consideration if data entry as part-year values is permissible (really provision of annual data would be more robust). For transport easily the most accurate input needed for any calculations is litres of fuel used or failing that spend on fuel for cars. People filling in a calculator may know how much they spend on vehicle fuel. This will be better than the bottom-up mode and distance calculations which will be harder to get the data for anyway. Also be aware the emission factors produced at some level of detail in Section 3 for transport may already exist e.g. in the UK they have for years as kgCO2e/km or passenger.km. This may well be the case for other countries. Indeed, these emission factors are heavily used by organisations undertaking annual carbon inventory reporting.
4.	The naming of the schemes is not something that has been given much prominence in the report. Section 2.2.2 demonstrates that this seems to have been only internally workshopped, no actual market testing was done. The most important piece of feedback here is that proper market testing should be undertaken here to understand what is best understood and liked by end users. In terms of what has been presented here, positive adjectives, alphabet/traffic lights, or plants have been proposed. Of these, the middle seems easily the most credible of the three, and has the advantage of already relating to current labelling schemes used in other parts of the economy. The plant scheme in particular seems quite random and likely to confuse. That said, this is perhaps the least challenging aspect of what is being proposed here. Producing a calculation method that accurately, comprehensively, and dynamically calculates carbon emissions is likely to be extremely hard and this should be focussed on prior to what then to do with the outputs of those calculations.
5.	This is a difficult question to answer, and depends on a number of things. Firstly, the current proposal is to look at three sectors (though really electricity and heat are a single “sector”, namely “household energy”). The number of questions will relate to the number of sections covered within the analysis. For reference, in Appendix A the identified CFCs range from a maximum of 72 to as low as 8 (or zero for IMPACT, though this sought to produce community not individual footprints so the results were based on other data sources and pre-processed for output). Typically, there seem to be approximately 20 to 40 questions. This is probably about right. Categories for Household Energy, Transport, Food, Goods and Services, and maybe Waste (though this is likely to be small in terms of carbon emissions, especially if no organic waste is being sent to landfill) might be enough and 5 to 10 questions in each section (depending on which, and given transport is likely to have sub-sections) is not unreasonable. That said also, if there is an ultimate aim of rolling out something like this across the EU in some sort of formal capacity, then there needs to be some serious upfront testing of both the number and nature of the questions being asked. It is also worth pointing out at some “questions” might have multiple options depending on what information is available to the user e.g. domestic electricity, there might need to be an upfront question about what data you have (amount spent, kWh used etc) then a specific follow-up question. The method of data entry also needs careful consideration and whilst Excel has been mentioned as an initial step, this is not likely to work when rolled out to the public. There is a wider issue that needs to be considered here though. That is, that there may be a difference between designing a series of standardised questions (like a census) that require addressing at regular intervals e.g. one year, or something that perhaps is quite intensive at the outset to establish a baseline, then actively engages users over time by prompting users on a series of issues. The advantage of this is that there could then be a more

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	direct link between the inputs and behaviour change as the tool can be used to "nudge" behaviour towards better outcomes. The Giki Zero tool does something similar to this, and it may be worthwhile the authors looking into an approach like this.
6.	The majority of comments have already been made in the previous sections. It is worth though reinforcing the two key messages at the heart of my feedback, and they relate to each of the underlying calculation approach (scope and method), and then the dissemination (labelling). AURORA appears to be set up with objectives to address the latter, though in fact is discussing both. Calculations Scope and Method: It is true that there is huge variety between currently available CFCs in terms of their scope and approaches and therefore it is not surprising that huge variations in results are being achieved for the same inputs. They are also in the main not transparent so it is hard to tell what is going on. There may be a case for attempting to create a unified standard for this, though it is also worth stating that whatever could reasonably be authored here would doubtless enable subjective interpretation of the sort we already see with the GHG Protocol and corporate footprinting, so this issue is not likely to go away. Notwithstanding all this, the AURORA team need to be quite sure that what they produce would in some way be an improvement on whatever is already out there, rather than adding to the considerable noise. Labelling: This is definitely an untapped area in terms of citizen footprinting reporting. It must be stated though, that this aspect should not be commenced until a robust calculation has been developed as this otherwise risks undermining everything. It is suggested that until a good sized body of results has been calculated from the calculations which would then enable analysis of the population data, the setting of thresholds should be paused. It may be possible to still do some market testing on the preferred visual appearance. Within this area, thought also needs to be given as to how this citizen labelling is a live process and not some set of inputs that are completed once and forgotten about. There are existing tools and apps that could be consulted for examples. PS It should also be stated that there are a number of instances in the report where there is a "reference could not be found" error, and so there appears to be some sort of issue with the automatic referencing in the word processing software.

Reviewer 10	
1.	I think there is a potential for behavioral change, although there are some challenges that, in my opinion, should be reviewed before assessing the usefulness of the new labeling system. First, one of the main barriers is whether people would use it – this depends on whether people know the app, the burden of filling out the questionnaires, and even who ends up registering (e.g., only people with low consumption levels). Second, whether people will pay attention to the information depends on the trust of the source of information, the fit with people's beliefs, and their self-efficacy (i.e., they can do something about it). Third, whether the labeling system is used to encourage a long-term behavioral change through habit formation or commitment devices.

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2.	I do not think the emissions estimation is a concern as long as the calculations are technically correct and use reliable assumptions. The most important concern is whether the communication is simple, helpful, and trustworthy, even if it is based on complex calculations. An example of this is the new nutritional warning label used in several countries (e.g., Araya et al., 2022). In addition, it is not clear why the new labeling system would use both carbon emissions and energy consumption, and not only carbon emissions. Both measures are rather abstract for people and require a comparison like the one provided by the labeling system. The three-sector aggregation aims in the right direction –simplicity– although it might be challenging to convey the message on how to reduce CO2 emissions. For example, a person might be close to zero emission in transportation, but in one of the bottom levels in electricity consumption, his/her classification might be in the middle. What does he/she do with that information? Perhaps adding customized recommendations based on people's responses can help them to know how to move to the next level in the labeling system. Araya, S., Elberg, A., Noton, C., & Schwartz, D. (2022). Identifying food labeling effects on consumer behavior, Marketing Science, 41(5), 871-1027.
3.	I am persuaded by the numerical ranges used in each category (from page 8). However, it is hard to assess whether the ranges of each category are appropriate because it depends on the distribution of the population. As a suggestion, I would run a simulation with data to understand how the distribution changes with different cutoffs. One of the goals of the categories is to incentive upward and downward comparisons. If people feel good about their actions in a middle category or that she/he cannot do anything to move toward an upper lever, the system might not be useful. This is why the system should provide clear actions to perform, so people can, for example, pledge to some of them and move to the next category. In addition, as I mentioned before, I would consider using only one measure (CO2 emissions) to make it more simple.
4.	If the goal is to incentivize upward comparison, I think the adjectives might better accomplish that goal. Perhaps I would suggest more neutral names at the lowest levels (e.g., beginner, elementary, intermediate) to encourage an upward comparison. On the other hand, using emoticons provides an injunctive norm (Schultz et al., 2007). In any case, I think this could be easily tested in a well-powered online experiment. Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2007). The constructive, destructive, and reconstructive power of social norms. Psychological Science, 18(5), 429–434.
5.	I think this is one of the main challenges of the new labeling system. Not only should the app consider the number of questions but how difficult it is to answer them – this latter point might drive significant attrition and uncertainty. As long as people have the tools to respond, the length should be a function of whether people are interested in answering each question (e.g., Marcus et al., 2007). Therefore, it would be useful if the app has a friendly interface that engages users, for example, providing feedback to maintain interest. This, again, could be experimentally tested to see how quality and attrition vary. Marcus, B., Bosnjak, M., Lindner, S., Pilischenko, S., & Schütz, A. (2007). Compensating for low topic interest and long surveys: a field experiment on nonresponse in web surveys. Social Science Computer Review, 25(3), 372-383.

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6.	I would suggest revising which behavioral framework to use based on past evidence, hopefully from the field and large samples. For example, the identity labeling literature would indicate that people should be told that they care about the environment based on their responses. However, this opens the question of how people would behave if they were told that they are "no green." In addition, I would recommend empirically examining some alternatives for improving the labeling system. In particular, the questionnaire (e.g., length and type of questions) and the output (category names and ranges), and whether it encourages a behavioral change or use of the app. Depending on the feasibility, this could be done with a couple of well-powered online experiments. Testing different alternatives to have an informed decision can save time and resources.

Reviewer 11	
1.	-Yes, I think that the proposed labeling system incorporated into an app could be a useful strategy for driving citizen behavior change. The labeling system is very well thought out and clearly designed. - Linking the citizen's behavior to an environmental label or achievement label can lead them to view their identity differently. The label is more likely to be accepted if it is linked to past behaviors, as it is in this app. - If they accept the label, this can boost their sense of intrinsic motivation to continue with behaviors, since they behaviors are now a part of their identity. It can motivate them to maintain behavioral consistency and to try to act in multiple ways that are emissions-reducing. This is important since if they accept the label, it can reduce moral licensing and the likelihood of negative spillover, where people do one "environmental good deed for the day" and then feel free to do other environmentally harmful things. - One thing that may lead the current labeling system to be less effective at motivating behavior change is - Some citizens are being given a label indicating that they are not yet environmental (those who are placed in a higher emissions level). These individuals may also take the label to heart, and it could lead them to perceive that they are non-environmental people. If they act consistent with this given label, then they would not try to reduce their emissions. It is true that upward social comparison might motivate them to change to obtain a lower-level label, but probably only if having an environmental identity is already important to them. - There is some promising research on "dynamic norms" that perhaps could inform how to frame the feedback for those who are using lots of emissions when they begin the app (e.g., Sparkmann & Walton, 2017). Information could be provided about how the norm is changing, and that more and more citizens (especially within this community) are starting to try to reduce their emissions. Even though there are not yet many Near Zero Emissions citizens, they can join in with others to start moving towards this direction. - This is less of a concern, but there is also the potential of unintentionally de-motivating those who are told that they are already at a very low level (have Near Zero Emissions), If the environmental identity is not important to them, the descriptive social norm could pull them towards using more emissions - they might interpret this as they are using far less than their peers and so they could actually use more if they want to. However, since the app gives them a positive label for using few emissions and the community events indicate that reducing emissions is valued by the community (injunctive norm is towards creating fewer emissions), then this may be less of a problem. It is clear that reducing emissions is preferred.

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	- From what was shared in the documents, It seems like there are two separate interventions – the app that is individually focused on providing feedback and labels, and the community events that are group focused on trying to get community members to engage with community-wide emissions reduction efforts. When the local community members engage in crowd funding for a local PV facility or participate in the emission-related activities hosted by the community, this has the potential lead community members to interpret that their social group really values the Near Zero Emissions identity that is the goal of the app. Observing or participating in these community activities could increase the individual's sense of obligation to also take personal action to reduce emissions. It seems like it would be worth thinking through how to make these connections between the community identity and app explicit. Perhaps similar branding could be used both on the app and at the local events.
2.	-I agree that keeping the approach to estimating emissions simple. My only concern is that these three categories might not be the best choices for the specific university communities being focused on. University students in particular often have less control over their electricity and heating than other adults since they either live on campus where these are controlled by the university, or at their family home where much of it is controlled by their parents or other family members. - I might suggest including the food sector, since this can represent a fairly large portion of each person's carbon emissions and university students often have more choice about this than the other sectors. However, I can also see how including food in the app would be difficult. It would either be very general, with each user indicating their food habits overall (they are vegan, vegetarian, pescatarian, omnivorous, etc.) or with each user answering time-consuming food questions that would need to be asked regularly
3.	- I think it is appropriate to set the "Near Zero Emissions" label on the goals from the European Climate Pact. I suggest that this should be explained in the app itself, so the users understand where the levels are coming from (so they do not seem arbitrary). I think this is also beneficial in that it makes the final goal at least somewhat attainable, rather than each user needing to transition to an off-the-grid lifestyle to achieve the Near Zero Emissions label. - I agree with using 5 levels. My assumption is that those users who fall into levels 1a and 1b would be given the same label (whatever the label for "1" is). Five levels allows for enough variability for the user to see progress. I am not sure, but I imagine that this might also be beneficial if it keeps most users out of the highest level of emissions use, and therefore allowing them to feel some level of pride in that they are not at the worst level/label. - I also agree with making the steps smaller closer to the middle, so that people can easily start to see progress and feel rewarded easily. The only downside to this is that it might actually take a lot of significant change for someone who is on the higher end of emissions usage to go from level 3 to 2. So it might be somewhat de-motivating for those who most need to make changes. - I agree that people should just receive one label, with the app designed to allow them to delve deeper to see their exactly levels in electricity, heating and transport separately if they wish to. What I found difficult to understand was how a level/label would be chosen for a person whose usage fell into

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	different levels for the three sectors. For example, what level would someone be shown on the app if their usage was at level 1a for electricity, 1b for heat, and 2b for transport? It seems like it would be worth averaging these to give the user a label somewhere around 2a or 1b rather than to make them stay down a 2b at the lowest level they met.
4.	- From the document, I can see that the team spent a lot of time thinking about how to label the levels, and I agree that the 'positive adjectives' or the 'plants' options could be good. I prefer them since there is the possibility to keep all the labels positive while building towards higher levels of leadership or greater amount of ecological awareness. Of the two, I think the 'plant' label's strength is that it makes the link between reducing emissions and helping the environment clearer. It can directly tie into the ecological and climate values of the community that is endorsing the campaign. The positive adjective labels do not directly evoke the environment. However, they could also be linked to the community social identity (you are a 'leader' in the University ____ community). - A suggestion – Perhaps the images associated with each label on the app could directly include the social community. For example, if the 'positive adjectives' are used, perhaps the image of the cartoonish person is wearing a University of ___ t-shirt. If the 'plants' are used, perhaps the images could be of the plant growing somewhere recognizable on the University of ___ campus. - My concern with the 'alphabet/color' label is that some of the labels will be inherently negative. If a user is given a negative label (letter F or red color), this might lead some to disengage and/or continue acting in the high-emissions ways that are consistent with that label, as I mentioned above. I think the 'plant' and 'positive adjectives' labels are less likely to run into this problem. - Since this term is not explicitly included in the suggested labeling schemes, I am not sure if it will be used. But the term "Near Zero Emission citizen" seems like a somewhat odd label. Even if an individual reaches the emissions reduction goals of the European Climate Pact, they are still using quite a lot of emissions – they are not "near zero." It also might be more motivating to give this highest level a title that is about them achieving something rather than having "Near-Zero" be the achievement.
5.	-I understand and agree that you want to keep the number of questions low, especially for items they may be asked to update regularly on the app. So keeping the number of questions low should be a priority. - However, one downside of only entering energy and heating data by general household consumption is that people often only receive this information monthly and the usage is spread out among multiple people. If the individuals are not getting feedback about their specific behaviors over shorter time periods, it is often unclear to people what behaviors they can personally change that will actually lower their energy usage. The example I like to use is this: If you only received one monthly bill for all of your family's food purchases, without itemized material about what each item costs, how would you know how to reduce your food spending? Perhaps a way to address this is for the app to include some tips about the behaviors that have the biggest

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	impact on reducing electricity, heating, or transportation emissions, and then asking people directly about a few of those behaviors along with their monthly usage? - On pg 25, it states that “a holistic app is being developed to engage citizens in a continuous way and provide them with such external reinforcement” but there is not very much explanation of how continuous feedback and reinforcement will work. I think this part is important for making the labels (and using the app) meaningful to the individual. One potential way to do this is to require users to enter at least some individual behaviors, especially ones that are the most impactful for electricity or heating. For example, everyone’s heating use will generally go up during winter months. If the app just reports that their emissions have gone up in winter and then pushes them to a new higher-emissions label due to this increased energy use, this would be less interesting and even frustrating for users. But if there were some individual energy behaviors they could report to the app, and then the app calculated how their relative increase in heating usage is lower than it would have been if they did not take these actions, that could be more motivating. - Perhaps there could also be a portion of the app where people could submit a specific energy behavior, and then learn how much electricity/gas/carbon is used. So for example, they could learn how much is used by leaving a TV on vs. running the clothes dryer, etc. This could be interesting and engaging to those who really want to learn more about how to best change behavior to reduce usage and emissions.
6.	- Many of the communities chosen are universities full of students. This may be a trickier population to work with for this app for a few reasons. (1) If they live on campus, they may be much less in control of their electricity, heating, and/or transportation choices, and may not have individualized electric or heating bills. (2) Whether students or faculty/staff – it seems like their energy use on campus should be included somehow in the app, since that is the environment in which they may first make changes to meet the community norms and they might get frustrated if those changes are not reflected in their app scores, (3) Students tend to be temporary members of the community – so they may start attending the university after the crowdfunding for the PV has already occurred and may not feel as involved in such projects. However, if there are regular energy intervention activities on campus, they can be involved in those. - In terms of motivating employees in particular, it seems like it might be important to indicate where money that is saved through reducing electricity and heating is going to be invested. Perhaps into the local PV project or other community interventions? Or perhaps towards student scholarships or a local fund for helping low income families pay their heating bills? If it is not indicated where the money savings are going, employees might be skeptical that the reason their employer is promoting energy savings is really to just save money rather than to promote a low-emissions future. - Another factor that might impact the actual behavior change promoted by the app is how important the local community social identity is for the citizens in the community. Is being a member of this university actually important to them? Perhaps part of the community interventions could be aimed at strengthening their social identity/connection to their group.

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	- I agree with making the app voluntarily, since that ensures that you have users who are at least somewhat interested in reducing emissions. They are also more likely to stay engaged and enter their data for a longer period of time if they have some intrinsic motivation. However, if it is voluntary, then it will limit the percentage of the community that is actually using the app, meaning that the overall community's emissions may not be reduced as much.

Reviewer 12	
1.	It could indeed be if used to support – and also drive - behaviour change provided the tool is communicated in a way that supports its use. The communication strategy and the context it is communicated in is extremely important, and needs to be very carefully considered in order to avoid misuse of the tool (e.g. by centralist governments to punish high energy use) or negative labelling of individuals. Thus, it is great that AURORA has an ethical component in the project to accompany the use of the tool/labelling system. It is also vital to consider individual vs. collective responsibility for lowering personal energy use and associated carbon footprints, and not to place too much burden/responsibility on individuals. There are well-recognised limits to what individuals and households can achieve, and the importance of structures and structural conditions for change need to be considered (as also noted in, though to a limited extent, in D1.1). There are individuals and households who regardless of how much they change their behaviour, will be unable to make sufficient reductions as the existing infrastructural conditions are not supportive (e.g. renewable energy is not available as the physical infrastructure is simply not available to purchase it through utilities, or financial incentives are not in place to support those not well enough to invest, or public transport is not available for commuting, etc.).For this reason, the communication around the tool and trough the tool is vital. Furthermore, in my view the mentioning of „ranking" and the ranking of individuals and households with the use of the tool and associated labelling should be avoided. Other points for consideration related to Q1: --You select the SHIFT framework for your own approach, which is fine. However, it would be useful to provide at least a brief reasoning for this as there are a lot of other behaviour change models/frameworks in use. You do acknowledge that there are other frameworks, and your objective is not to provide a review, still, it would be useful to provide a bit more reasoning for your choice. --In my view and experience, taking advantage of groups in various ways to support behaviour change is a very good approach. However, perhaps other group-related factors should also be considered like social norms, traditions, expectations, etc. that influence behaviour (the SHIFT frameworks also mentions them, but they are not emphasized in your approach).In this regard, social practice theory may also provide further valuable insights especially related to placing less responsibility on individuals, and more on understanding why we perform certain activities the way we do, and as a result why we use so much energy. A useful input for this could be the ENERGISE project (H2020) and some of its outputs and publications (see at https://energise-project.eu/). --On pg. 5. you propose that the tool should enhance environmental self-identity. This, obviously, I agree with. However, could there be a way to extend this? For example, what about using the tool to reach those who save energy mainly, or purely, for financial reasons and may not really have developed

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	their environmental identity? The tool and associated label could be useful for them, too, as they could monitor their energy use reduction. If you managed to involve these people and communities as well, the tool could reach more people, and could also be relevant to more (diverse) communities. It would also help those not yet environmentally aware develop their environmental identities through realizing that saving energy does not only save you money, but can also help you become more environmentally aware. This may be obvious to those of us working in the field, but certainly not (yet) to great sections of society. --You claim that you will achieve long-term citizen engagement (pg. 3.). However, it is not shown how exactly you will achieve this with your tool/labelling. It would be useful to see a strategy for using the tool/labelling in practice. What kind of engagement and communication activities will be there to support its use? You mention that multiple drivers are needed to support behaviour change, which I absolutely agree with, but what will these multiple drivers be in your specific case? Some are mentioned in D1.1, and perhaps you are developing a more detailed strategy for this in another WP, my main point is that it needs to be considered carefully.
2.	I agree to keeping the estimation simple. I do not agree with limiting it to three sectors and still calling it “near zero emission citizen label”. A considerable part of our energy use and emissions are linked to nutrition and our food/diet choices, the amount of products we buy, the kind of services we use, etc., so limiting the label to three sectors and still calling it “near zero emission” is very problematic (see also my further comment below about the universal, fair and sustainable carbon footprint objective). I do understand that limiting the label to the three sectors may be a necessary pragmatic decision at this stage due to the complexity of gathering reliable data, etc. However, if this decision is made, the name of the label should be changed to reflect this choice and approach, and ensure that those who use the label/tool do not mistakenly think that they have dealt with all aspects of their emissions. If they do not clearly understand this, the label may even have a negative impact in that it misleads its users about their personal emissions. The graded label is great, though, I agree that it is much better than a positive/negative label. A further, very important consideration is the fact that you set different values for different countries, even for the lowest consumption category/footprint. This does not seem fair at the European level as it allows certain countries and their citizens to have higher footprints while others have lower, and does contribute to preserving inequality. At the same time, the label suggested by you, if implemented well and if the reduction values and relating categories are selected well, could indeed contribute to achieving higher levels of equality within and across countries as well. I do understand your reasoning for selecting different values for different countries, and I also understand the challenge of converting sustainable carbon footprint objectives to consumption data (kWh). However, since this is a European project, and a European system, and, vitally, our objective should be to lower per capita footprints to a globally low, fair and sustainable carbon footprint, which was defined in the UNEP Emissions Gap Report (2020) as 2.5 tons/cap by 2030 and to 0.7 tons/cap by 2050, the ultimate aim should be to reduce to this value in all countries in order to reach the 1.5 °C goal set in the Paris Agreement (as an additional resource, including for methodologies, please see the technical report on 1.5-Degree lifestyles by Akenji et al., 2019). Obviously, the 2.5 and 0.7 values refer to the full footprint, so the approximate relevant values need to be calculated (the EU 1.5° Lifestyles (H2020) project or other currently ongoing European research projects may have some relevant data, not yet published, though).

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	Other points for consideration related to Q2: Have you considered using the Exiobase database for comparable emissions data? (https://www.exiobase.eu/index.php/about-exiobase)
3.	In my view the lowest categories are not ambitious enough – regardless of their alignment with Green Deal objectives. Please see my comments regarding the necessity for a more universal/global overall reduction target above. The sum of the carbon footprints to be achieved by adding the values of the lowest categories in each consumption domain ought to be the same across countries. Thus, I do suggest the revision of the current categories along these lines. Obviously, different starting points and reduction paths are needed for different countries, but the lowest category, the overall objective should be the same in my view (this reflects the “contraction and convergence” approach also used as one of the conceptual underpinnings of the Kyoto protocol).
4.	I rather like the idea of a naming system based on plants, and the bigger the plant the smaller the footprint is. It would be important to select local, native plants for these, and by no means non-native or even invasive species. In addition, to emphasize the diversity across countries, I can imagine that the plants, including the largest plants, probably a tree, is not the same species in all countries (though it could also be the same, e.g. an oak tree). Furthermore, if you decide to use plants, maybe a colour scheme becomes redundant, which may actually be a good decision so as not to discourage those citizens who are in red to begin with. Other points for consideration related to Q4: --Although people like labels, there is usually also a certain level of scepticism, and lack of trust in them. Have you considered this for the identity label suggested? Do you have a plan for establishing and increasing trust in the label? --An existing label/classification scheme, the home energy certificate would also be a relevant labelling scheme to study in relation to the identity label. Is there a reason why you have not considered it? It would be especially relevant as it, indeed, ranks homes based on their energy performance, so it may provide some useful insights for developing the identity label in AURORA.
5.	In my view, in order to have trust in the system, i.e. the APP and the label, through being able to communicate reliable data, it is better to ask more questions from users. If they are warned when they start, and they do not necessarily need to fill in everything in one go (i.e. they can return to the APP once they find the data), it is OK to ask for more information. You can also consider making your input data questionnaire available as a downloadable document so that users can study it, assemble the necessary data, and then input it. Also, there is need to distinguish between initial input data, and monitoring consumption data, which are different. You will need a lot more initial input data (e.g. about heating systems, fuels, household size, vehicle parameters, etc.), but then for monitoring a lot less, unless something changes. Consequently, most probably some of the data will be more challenging to find for users when they first start using the APP, but it will be a lot easier as they carry on using it. You can inform them about this as well so that they do not get discouraged. As for the exact number of questions, I do not have an absolutely concrete recommendation. In the calculators we have used in our programmes (both energy consumption calculation and carbon footprinting) they easily need to fill in information for 25-40 questions to begin with, sometimes even more,

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	depending on the detail we aim for. But as they go on using the calculator, they usually just need to supply their consumption information, and only adjust other information (e.g. household size, fuel used, etc.) if there is a change. --Informing them in advance clearly about what to expect is key for success. --And it is useful to prepare easy-to-use guides for finding the necessary information. In our experience, people often do not have any idea about how and where to find their consumption data, especially if they pay a flat rate energy price. Other points for consideration related to Q5: --You may need slightly different data input forms for different countries depending on the local energy systems in the country, i.e. the energy sources used, the heating technologies applied, measurements and monitoring or invoicing systems used, etc. This is what we experienced in the EnergyNeighbourhoods project where we designed a calculator covering 16 European countries. Thus, it will be very important to map, by country, all fuel sources, heating technologies, the way they are accounted for (i.e. measurement units used, etc.), and how they can all be then converted to the same unit by the APP. --You could consider allowing users to first just input data in one domain (e.g. mobility), and then add more domains as they get used to using the APP.
6.	Some carbon footprint calculators and carbon footprint related publications provide footprints in CO_2 and some in CO_2e. You do not mention this difference in D1.1. However, once the deliverable is made public and your tool goes live, it would be useful to include an explanation for your choice regarding this issue. This would be all the more important so that citizens are aware that their actual footprint is most likely higher than calculated through the app/label. Several European projects focused on involving citizens and communities of citizens in measuring, monitoring and reducing their energy consumption and associated carbon footprint. Various methodologies have been used, and reports made on challenges encountered and strategies made on overcoming them. From the current report, I miss a review of at least some of these projects and lessons learnt. It is possible that representatives of these projects have been contacted and interviewed, but it may be worth mentioning them in this report. (Many other projects exist, but some of the projects I was personally involved in that used relevant methodologies are o the EnergyNeighbourhoods project, which was an IEE funded project in many countries, but was implemented outside European funding for many years in Belgium and Hungary; o the Compete4SECAP H2020 project and save@work IEE project, which targeted public employees, but nevertheless used relevant calculation methods.) Have you considered how and what to communicate to citizens who are already in the lowest category? That maybe some of their experience, specific everyday behaviour and consumption choices could be communicated as examples?

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	On pg. 24. you are making the assumption that the emission factor of national energy systems will be decreasing. Because of the war in Ukraine, you may need to revisit this assumption as some countries are reverting back to dirtier fuels such as coal, lignite, etc. References: Sparkman, G., & Walton, G. M. (2017). Dynamic norms promote sustainable behavior, even if it is counternormative. Psychological Science, 28(11), 1663-1674. https://doi.org/10.1177/09567976177199

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