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How to reduce individual environmental impact? A literature review into the effects and behavioral change potential of carbon footprint calculators

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Summary

S.1. Introduction

Many of our daily activities - such as using electricity, driving a car, or buying and disposing of products - cause greenhouse gas emissions. Together these emissions make up an individual's carbon footprint. Our current Dutch average personal carbon footprint is too high. In order to reach the Paris Agreement climate goals we have to lower our personal carbon emissions by around three-quarters within the next ten years. This kind of reduction will have a huge impact on personal lifestyles and asks for drastic changes in our society. Different kinds of changes in our behavior and lifestyle are needed: changes in consumption behavior (such as avoiding airplane travel) as well as changes in collective behavior (such as becoming active in a local energy community or environmental organization).

To reduce carbon footprints people need to, amongst other things, be informed and engaged, for example by means of a carbon footprint calculator. Carbon footprint calculators are designed to estimate one's personal carbon footprint and provide users with personalized feedback on how they score and how they can improve. It is assumed that this tailored information will lead to a change in consumption, and at first sight carbon footprint calculators indeed seem to have the potential to change behavior. But we wanted to know whether or not this actually is the case. In this report we therefore investigate what is known from previous studies about the effect of carbon footprint calculators on awareness and behavior (research question 1). Since we expect that the more elaborate work field of health psychology could provide us with insights on effective interventions, we look at the field of health psychology and health related interventions to find ways how to improve footprint calculators to become more effective in changing behavior (research question 2).

S.2. Method

We performed a literature review on two main topics: carbon footprint calculators and health interventions. We focused on finding the most relevant studies. In total we included 12 papers on the effects of a carbon footprint calculator, and 26 papers on health interventions and behavior change. Furthermore, we made an overview of various carbon footprint calculators that are globally developed.

S.3. Insights from previous studies

The studies in the selected papers provided us with insights on the effect of carbon footprint calculators, and of health interventions. The main insights are summarized in the two tables below.

Insights from footprint calculators studies
1. There is little high quality research into the effects of carbon footprint calculators
2. Carbon footprint calculators can lead to changes in awareness and behavior
3. But carbon footprint calculators are sometimes also ineffective
4. Only a small group of people is interested in calculating their carbon footprint
5. Taking away implementation barriers can lead to progress in changing behavior
6. Personal carbon emission goals can be perceived as out of reach
7. Carbon footprint calculators need a content update

Insights from health intervention studies
1. Combinations of specific behavior change techniques are most promising in changing behavior
2. Concrete feedback can lead to the desired behavior
3. Only changeable factors should be targeted
4. The design of the physical and social context is important
5. The focus should be on behavior maintenance instead of short term change
6. Short term gains should be included to motivate people
7. Tune in to the different phases of behavior change

S.4. Main conclusions

Merely providing personalized information on carbon emissions seems insufficient

The literature on the effects of carbon footprint calculators on pro-environmental behavior is limited, studies are often of low quality and they present mixed results. The available studies show that carbon footprint calculators are effective in increasing knowledge and awareness, but providing people with only personalized information seems insufficient to encourage people to act more pro-environmentally and reduce their footprint.

Effective carbon footprint calculator approaches also include intensive guidance and frequent contact with and among participants, specific and comprehensive feedback on what people could do reduce their footprint, reminders during a longer period of time, specific goal setting and reinforcement of progress. In other words, the approaches were more than merely filling in a footprint calculator. But as there is a lack of high quality studies, drawing strong conclusions on the best approach is not possible.

Insights from health interventions can improve interventions aimed at encouraging pro-environmental behavior

Although there are differences between health and pro-environmental behaviors, for example improving one's health leads to more instant personal benefits, we expect that successes from health interventions can be applied to encourage pro-environmental behavior as well. Carbon footprint calculators can benefit from including more behavior change techniques than are used in current approaches.

There is however not one most effective intervention blueprint, but there are several promising ways to improve impact on behavior. The literature on health interventions shows that especially interventions that combine motivation-enhancing techniques with a technique explicitly provoking persistence, such as the use of follow-up prompts (notifications like SMS), are promising.

Generally speaking, people's motivation to actually lower their carbon footprint is low. Although people often have 'green' intentions, they are mainly prepared to make 'small', convenient changes to lower their footprint. Studies additionally show that carbon footprint calculators are used by only a small group of people. For this motivated group motivation can be enhanced by pro-environmental arguments and linking to their so-called biospheric (green) values. For the others, different kinds of motivations, values, or benefits should be addressed such as saving money, improving health, self-improvement or stewardship. Similar to improving healthy

lifestyle choices, pro-environmental behaviors are about long term gains that (often) ask for short time investments that can be perceived as a loss. A focus on short term *gains* could be a promising avenue to motivate this particular group, especially in combination with other values and motivations than acting pro-environmentally. Short term goals could for instance be improving one's health because of using a bicycle or eating, enlarging one's family time because of working at home, or a credit gaining system within an intervention.

To maintain behavior change individuals need at least one sustained motivator. These may include behavior enjoyment, satisfaction with behavioral outcomes, self-determination or an experience of behavioral congruence with beliefs and values, all of which often develop after initiating a new behavior. Having people gradually taking steps towards a sustainable lifestyle (graded activity) that fits their actual situation could be part of an effective approach.

Current carbon footprint calculators can be improved
Our review shows that merely providing carbon footprint outcomes will not lead to people lowering their footprints, but offering information is a fundamental part of the process of people considering changing their behavior. Weekly or daily carbon footprint information (i.e. frequent reminder) with a specific cap/target (i.e. goal setting) could be part of a fruitful approach. Already existing daily carbon footprint calculators could possibly be used for this purpose. When these footprints are provided as part of a larger approach in which a combination of behavior change techniques is used, and the social (e.g. family and peer support) and physical environment (e.g. product and service availability, infrastructures) are in some way aligned this could lead to positive effects on people's a lifestyles.

S.5. Way forward

We identify several options to move forward, in practice and in applied research.

Practical application
Use carbon footprint calculators as part of a national communication plan
When people receive personalized information about their own impact, they get to see an integral picture of what causes CO_2 emissions. Moreover, personalized information shows them how they can lower their footprint. We would advise not to only provide tips that focus on individual action (such as buying solar panels), but also on collective actions (such becoming active in local initiatives), to avoid feelings of helplessness and enhance a social movement.

Integrate carbon footprint calculators in a broader intervention
For the best results we recommend to integrate carbon footprint calculators with broader interventions, such as programs that combine motivation-enhancing with provoking persistence and adding social aspects. Adding goal setting elements to such an intervention could be fruitful. Furthermore focusing on short term gains and on how to improve, could motivate many people regardless whether they hold pro-environmental values or not.

Research
A large scale study into the effects of footprint calculators
Our review on carbon calculator studies showed that there is a lack of good quality studies into the actual effect of carbon footprint calculators on behavior. We think it

would be useful to do a large scale study with a test and control group, using a representative sample of society. In the test group the effect of the broader intervention as described before could be analyzed.

Research effects of the daily or weekly use of footprint apps
The effect of a regular (daily or weekly) use of footprint apps has not been studied. We believe these kind of apps do have potential because reminders by an app can create daily interaction and elongate the period in which people are engaged with the subject of reducing their carbon footprint.

Research effects of using footprint calculators on support for environmental policies
Next to designing interventions aimed at individual behavior there are other ways to encourage pro-environmental behavior, including implementing government policies that encourage, restrict or tax certain behavioral options. To successfully implement these policies they need sufficient social support, as when there is a complete lack of support for specific policies compliance will be problem. Since there has not been any research on the effect of carbon footprint calculators on policy support (such as signing a petition or contacting a politician), we suggest this as an avenue for further research.

Research on the perception and effects of a personal carbon budget
The idea of a personal or household carbon limit (that could be used in a personal carbon trading scheme) has been proposed but has not yet been properly worked out. We would be interested in investigating how people feel about the concept and implications of the personal carbon budget, and test how people would use such a budget.

Explore the integration of carbon footprint with a “happiness calculator”
Carbon footprint calculators only appeal to small percentage of the Dutch citizens. Another avenue to explore is to integrate the carbon footprint calculator with a so-called happiness calculator. This is another type of motivation (personal growth) which would appeal to another group of people.

Contents

1 Introduction

1.1 Our current footprint is too high

Many of our daily activities - such as using electricity, driving a car, or buying and disposing of products - cause greenhouse gas emissions. Together these emissions make up an individual's carbon footprint[1]. In the Netherlands the current average carbon footprint of a person is about 10 thousand kilograms (or 10 ton) CO_2e per year (Milieucentraal, 2019)[2].

According to a recent report on scenarios reducing carbon footprints to keep global temperature rise within 1.5 degrees, we need to aim for per-person consumption-based greenhouse gas emissions targets of around 2.5 (ton CO_2e) in 2030, 1.4 by 2040, and 0.7 by 2050 (IGES et al., 2019). In other words, within the next ten years personal carbon emissions in the Netherlands would have to lower by around three-quarters. This kind of reduction will have a huge impact on personal lifestyles and asks for drastic changes in our societies.

1.2 There are differences in footprint between countries as well as individuals

In 2018, inhabitants of other European countries had a carbon footprint between 4.4 ton (Malta) and 17 ton (Luxembourg) CO_2e per person (EEA, 2018). Globally there is more variation: for example, Japan: 7.6 ton, China: 4.2 ton, Brazil: 2.8 ton, India: 2.0 ton (IGES et al., 2019), Qatar: 49 ton, Australia: 17 ton, and the US: 16 ton (Our world in data, 2017). On a list of countries from highest to lowest per person greenhouse gas emission, the Netherlands ranks 25th (Our world in data, 2017). Of the 26 European countries from high to low emissions the Netherlands ranks 6th (EEA, 2018).

Also within countries there is variation in personal carbon footprint size. Socio-economic factors such as income, household size, education, dwelling size and basic consumption explain part of this variation (Ivanova et al., 2017; Ivanova & Wood, 2020). Especially people's income level has proven to be an important predictor of their energy use (Gatersleben et al., 2002; Vringer and Blok, 1995) and CO_2 impact (Moser and Kleinhückelkotten, 2018; Nässén et al., 2015).

Corresponding house sizes, possession of appliances and consumption patterns (energy intensive goods) lead to higher carbon emissions (e.g. Oswald et al., 2020; Rooijers and Smit, 2016). These variations show that reducing CO_2 emissions is a possibility for individuals.

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1 Although the term ecological footprint already existed, the carbon footprint concept was popularized by a large campaign by BP in 2005 (e.g. Kaufman, 2020).

2 There are different types of greenhouse gases (GHGs), including CO_2, methane, and nitrous oxide. These GHGs differ in the extent to which they contribute to global warming. As CO_2 is the most abundant GHG (but not the strongest) the impact of all other GHGs is recalculated according to their equivalence to the impact of CO_2. This is what CO_2e stands for.

1.3 Changes in our behavior and lifestyle are needed

To achieve the described per-person consumption-based greenhouse gas emission targets, we will need to change the way we live our lives. Three main approaches can be distinguished: absolute reduction, efficiency improvement, and modal shift (IGES et al., 2019). Absolute reduction means reducing physical amounts of goods or services consumed, such as food, kilometers driven, energy use, or living space, as well as avoiding unsustainable options. Absolute reduction is sometimes labeled as sufficiency. Efficiency improvement is about decreasing emissions by replacing technologies with lower-carbon ones while not changing the amount consumed or used, such as in energy-efficient agriculture, vehicles, or housing.[3] Finally modal shift means changing from one consumption mode to a less carbon intensive one, such as in adopting plant-based diets, using public transport, or renewable energy for electricity or heating.[4]

Regarding modal shift Wynes and Nicholas (2017) recommend thee individual high-impact (i.e. low emissions) actions with the most potential to contribute to systemic change and substantially reduce emissions: living car-free, avoiding airplane travel and eating a plant-based diet. An additional high-impact action they recommend is having one fewer child.

Next to pro-environmental behaviors that have a direct impact on a person's lifestyle and footprint, there are other behaviors that go beyond one's individual footprint and affect emission reduction on a local or country level. Stern et al. (1999) described green citizenship and supporting climate policy as other types of pro-environmental behavior. Voting for a political party with a green agenda, getting active in a green party or an environmental organization or writing to politicians are effective in reducing environmental pollution (Wynes, 2019). For example, when green parties have a stronger position are in a country, lower levels of air pollution are more likely (Bernauer and Koubi, 2009; Neumayer, 2003). Moreover, if there are active environmental groups present, nearby individual power plants have lower emissions (Grant and Vasi, 2017). These green citizenship behaviors may impact a person's footprint by changes in policies, which for example enable or encourage individuals to behave environmentally friendly.

In the Dutch media there is an ongoing debate whether individual behavior change should be encouraged, or whether we could better focus on systemic change (e.g. Tielbeke, 2020; Bregman, 2020). Putting the focus on individual action can indeed be a lobby strategy adopted by commercial parties to shift responsibility from their high emission business activities to consumers, while at the same time keeping business as usual and influencing consumers towards consumption by advertising or lobby. But in our view individual behavior versus system change is a false contradiction: they are both equally important to achieving the Paris goals. A mindset that removes this conflict or contradiction is that of individuals as part of "the system". Individuals contribute to change by for example their vote, their

[3] When proposing energy efficiency measures the rebound effect is often overlooked. That is, improvement in energy efficiency for a particular energy service reduces the effective cost of this service and this results in an increase in consumption of the same (direct effect) or another (indirect effect) service (e.g. Aydin et al., 2013; Verboven and Vanherck, 2016). The rebound effect is commonly estimated as in between 10 to 30% (Chitnis et al., 2013).

[4] Sufficiency and modal shift behaviors can also lead to rebound effects when people save money and spend this money on products and services (e.g. Sorrell et al., 2020).

activism, their (professional) jobs and by being an example to others in their daily behaviors. Industry focuses on customer demand and politicians are sensitive to the support of voters. An individual can therefore show industry and politicians there is demand for sustainable products and services, and support for environmental policies. Although it may seem that a single individual can make little change, the power of social influence is quite strong, and has been an important driver of (societal) change (e.g. Frank, 2020; Sunstein, 2019).

1.4 Communication efforts can stimulate change

We know that people worry about environmental problems (e.g. Dreijerink and Peuchen, 2019) and many people have the intention to behave sustainably and are of good will, however people find it difficult to contribute to reducing the problem. As Robert Gifford (2015, p28) put it: “By now, most reasonable people understand that they have been burning too much carbon. Most of these same people are still burning too much carbon”. How to overcome this inaction is an important question, and was the starting point of this current project and report.

As part of reaching climate mitigation goals from the Paris Climate Agreement communication directed at citizens is needed, with the following two aims: 1) To inform: communication can help citizens to gain insights in the issues and problems at stake and to understand policies implemented by the government. It can answer questions like: Why is it needed to spend community money on subsidies for house insulation, or to other (larger scale) changes? 2) To provide actionability: communication can provide information on how people can contribute to the climate goals themselves. The energy transition partly depends on the willingness of many people to invest in e.g. solar panels and insulation. A carbon footprint calculator is an example of a communication instrument that both provides information and actionability.

Studies show that people are mostly ignorant (or illiterate) about the environmental impact of their behaviors, for instance regarding food choices or energy measures (e.g. Attari et al., 2010; Bilharz and Schmitt, 2011; Gorissen and Weijters, 2016; Wynes et al., 2020): people do not know how much impact these behaviors have and overestimate the environmentally friendliness of their actions. Thus providing them with this information seems like a natural first step. Ignorance is one of the 33 so-called ‘dragons of inaction’ or reasons why people do not act that Gifford (2011) describes. As Wynes et al. (2020) conclude, consumers seeking to balance their carbon budgets may benefit from external aids to guide emission-related decision-making. A carbon footprint calculator could therefore help slay this dragon.

1.5 Calculating carbon footprints has potential to stimulate reduction

Carbon footprint calculators are developed to estimate one’s personal carbon footprint and provide users with personalized feedback on how they score and how they can improve. It is assumed that this tailored information leads to a change in consumption.

At first sight carbon footprint calculators seem to have potential to change behavior. According to the well-known behavior change model COM-B (see Figure 1) three groups of factors have to be in order to change behavior: people have to be capable, motivated, and opportunities should be presented to them to engage in the behavior (Michie et al., 2011). Carbon footprint calculators can especially tap into capabilities and motivation.

Carbon footprint calculators can increase psychological capabilities
Carbon footprint calculators especially contribute to the “capabilities” part, that in turn consists of physical and psychological capabilities. Providing tailored information that change is necessary (“your footprint is too high”), in which domains (e.g. “your high footprint is partly the result of driving your car for short distances”), and how (“taking your bicycle for short distances will lead to an x reduction of your footprint”) improves people’s psychological capability to make low carbon decisions. These insights can be real eye-openers for people. This also holds for example for people learning that CO_2 emissions to produce consumer goods is a substantial part of one’s footprint. In addition providing people with personalized information can also improve people’s self-efficacy: their confidence to be able to successfully carry out a particular task or solve a problem (‘I think I can do it’).

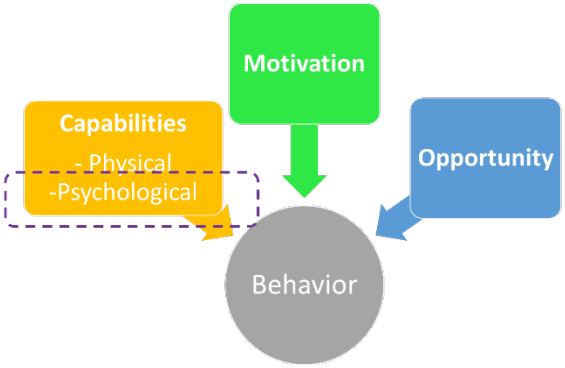

Figure 1 COM-B model. Footprint calculators are expected to contribute to the psychological capabilities of people to engage in sustainable behavior.

Footprint calculators link behaviors to the motivator “prevention of climate change”
Additionally, carbon footprint calculators link behaviors to the prevention of climate change, which is a motivator for a specific group of people. Insight in one’s carbon footprint is therefore expected to have an effect on consumption behavior, for example on buying solar panels, and/or on attitude towards policies promoting enabling or enforcing change, for instance supporting solar panel subsidies.

Moreover, the option to set goals for one’s footprint is an important motivator for change. For example by setting a cap or a limit on one’s weekly or daily carbon emission to get to the 2.5 (ton CO_2e) in 2030: what would be needed to reach that goal? The integral picture of the carbon footprint helps people to make changes within the entire width of their lifestyle (food, mobility, energy use, etc.). This daily or weekly engagement can be an additional motivator to change both frequent (daily or weekly) behaviors as yearly or one-time behaviors.

In sum, carbon footprint calculators have the potential to influence a number of determinants that are important for behavior change. At the same time we expect carbon calculators probably need to be expanded with other ingredients. In theory they seem like a sensible way of engaging (a subset of motivated frontrunner) people with pro-environmental behavior. However, we still wonder if they really are effective in reducing people's footprints in practice.

1.6 Research questions

We formulated the following two research questions:

1. What do previous studies show about the effect of carbon footprint calculators on awareness and behavior?

To answer this question we look at effect studies concerning carbon footprint calculators.

2. Are there ways to improve footprint calculators to become more effective in changing behavior?

For this second research question we look at lessons learned in the field of health psychology. Environmental psychology regularly looks at the research field of health psychology that has a longer track record and has tested interventions to a larger extent.

1.7 The setup of this report

In the next (second) chapter we describe the methodology of our literature review. In the third chapter we provide an overview of studies that investigate the effects of various carbon footprint calculators and sum up the main insights. In the fourth chapter we focus on insights from studies on health interventions, that are in some ways similar to carbon footprint calculators. Finally we draw up a number of conclusions about the potential of carbon footprint calculators and about ways forward, both in practice and in research.

2 Method

We explored two lines of research: carbon footprint calculators and health interventions. We did not perform a structured literature review in which all papers with specific key words were read, but we focused on finding the most relevant studies.

First, we searched for studies on the effect of using a carbon footprint calculator on behavior. We started our literature review by selecting scientific articles from our own literature archives. In addition, in April 2020 we did a Google scholar search on the topics ‘carbon footprint’, ‘carbon calculator’, ‘carbon app’, and ‘personal carbon allowance’. By means of the snowball method (investigating the reference section of articles) we found additional papers. We found eight papers that included studies into the effect of a carbon footprint calculator or a similar approach on behavior or behavioral factors. In addition, four papers explored the behavioral aspects of footprint calculators without an actual effect study. In total we included 12 papers.

Furthermore, we searched for footprint calculator websites and applications (from February 2020 to April 2020). For instance in the Google play store. We found 20 different footprint calculators. The effects of these calculators have not been studied and they are therefore only mentioned sideways in this report. An overview of the 20 apps and websites can be found in Annex A.

Second, we searched for articles summarizing the effects of health interventions. Again we started our literature review by selecting scientific articles from our own literature archives. Moreover we received papers from a colleague working on health interventions. Furthermore, in May 2020 we did a Google scholar search only on the topic ‘health app’. Again we applied the snowball method. In total 26 papers on health interventions and related were included in our desk research.

3 Studies on carbon footprint calculators

3.1 Carbon footprint calculators

A carbon footprint calculator enables individuals to self-estimate carbon footprints, self-manage behavior, and accordingly self-control carbon emissions (Lin, 2017). A carbon calculator is a way to provide people with personalized information on the carbon impact of their behavior. There are many different carbon footprint calculators online (see for examples Appendix A). For example, the Belgian smart phone app For Good measures a total ecological footprint (food, mobility, and energy use) and shows what to do to live more sustainable on a weekly basis (see Figure 2). Another example is the calculator by the Dutch website Milieu Centraal that provides a yearly overview of one's footprint regarding energy use in home, car and public transport use, flying, food and clothing (see Figure 3).

Figure 2 For Good app calculator

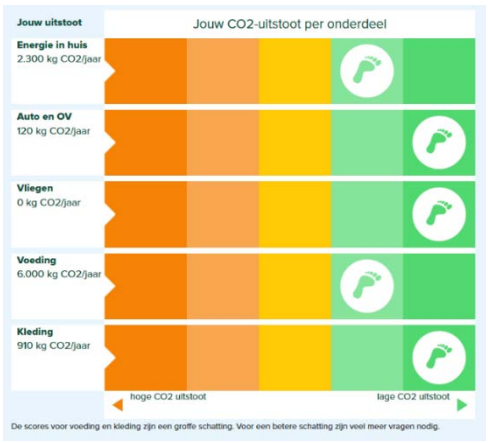

Figure 3 Milieu Centraal carbon calculator

Many of the online calculators differ in scope, including for example carbon emissions (carbon footprint), water use (water footprint), or resources and land-use (ecological footprint). In this study we merely focus on carbon footprint calculators. Moreover, carbon calculators differ in approach, from excel sheets, to websites, to apps. Furthermore, some calculate people's impact based on geodemographic information and self-assessed frequency of behaviors multiplied by their carbon impact (e.g. West et al., 2016), while others try to more objectively assess one's carbon footprint derived by financial transactions (e.g. Andersson, 2020). Comprehensive calculators illustrate what matters: typically housing, travel and food make up roughly three quarters of the footprint (Salo et al., 2019). Additionally, goods and clothing make up the main part of the other quarter (Porcelijn, 2016).

The scientific literature provides two streams of studies on carbon footprint calculators (Salo et al., 2020), that both build on the assumption that the information provided by the calculators would lead to a change in consumption patterns.

The first stream focuses on calculation methodologies (e.g. Birnik, 2013), and inconsistencies or improvements of calculators (e.g. Mulrow et al., 2019; Padgett et al., 2008). This stream of literature has concluded that transparency, consistency and data quality should be greatly improved. Padgett et al. (2008) for instance

found that carbon calculators can generate varying results often by as much as several metric tons per year per individual activity.

The second stream focuses on calculator use in empirical studies that aim to change the consumption patterns of households and individuals. In this report we focus on the second stream to answer our first research question: what do previous studies show about the effect of carbon footprint calculators on awareness and behavior?

3.2 Studies on carbon footprint calculators and behavior change

Of the 12 papers on behavior and carbon footprint calculators, seven actually measured the effect of calculators on behavior (namely Aichholzer et al., 2012; Büchs et al., 2018; Gram-Hanssen and Christensen, 2012; Hunter et al. 2006; Laakso and Lettenmeier, 2016; Lin, 2016; Sutcliffe et al., 2008). The quality of the seven studies on effects on behavior change varied. For some studies the sample sizes were quite small. Moreover, various researchers made use of convenience samples (e.g. students), or studied only people with an high interest in the topic or existing users of a calculator. Only two studies made use of test and control group. Finally, many studies relied on self-reported behavior (change).

The five other studies focused on determining underlying psychological factors of calculators (Salo et al., 2019; West, 2016), investigating predictors of calculator use (Chatterton et al., 2009; Lin, 2017) and exploring calculator usability (Mallett et al., 2013).

In the next paragraphs we describe the studies in more detail (the main characteristics of the 12 studies are summarized in Table 1. Most studies measured the (self-reported) effect on behavior. In the text we make a distinction between studies that did find a positive effect on behavior and studies that did not find behavioral effects. After describing the behavioral effects of the twelve studies, we describe which behavior change techniques they included and how other behavior related factors play a role.

Table 1. Description of the twelve studies in our review: authors, description of the calculator, the design of the study and the found effects.

Nr.	Authors	Description of the calculator	Target group and method	Effects
1	Aichholzer et al. (2012)	Online and offline carbon calculator (e2democracy tool) on: Energy supply (electricity and heating), mobility, nutrition, consumption. Self-report.	Calculator users (n=222) in Germany, Austria. Survey in combination with data collection in calculator over two-year period. Questions on awareness, knowledge, effort and behavior.	Awareness was raised. Footprints were smaller.
2	Büchs et al. (2018)	Carbon calculator interview on: heating, lighting, appliances, car travel, other surface travel, air travel and household goods. Self-report and energy bill.	Households (n=218) in South-Hampton, UK Field experiment (RCT) with test group (n=95) and control group (n=123). Eight surveys over two-year period. Questions on attitudes and behaviors.	Awareness was raised. Footprints were **not** smaller.

Nr.	Authors	Description of the calculator	Target group and method	Effects
3	Chatterton et al. (2009)	Carbon calculators in general, no specific type. On; various categories, main focus on transport. Self-report.	Explorative study. Expert interviews (n=8) on good practices for communicating environmental information. Carbon calculator user interviews (n=20), on accessibility and usability. 15 focus groups (n=8-10) with non-users of carbon calculators	Not an effect study.
4	Gram-Hanssen and Christensen (2012)	Map my Climate website on: heat, electricity, automobile transportation, nonfood commodities, air travel, use of second home, and food. Self-report.	Calculator users (n=220) Questionnaires on use of website, how it had influenced them, attitudes and knowledge about climate change, everyday behavior before the visit. Q2 on change filled in by n=99 (two weeks later). Three focus groups (n=18) on website content.	Awareness was raised. Footprints were **not** smaller.
5	Hunter et al. (2006)	Diary recordings in a spreadsheet EF calculator (Wackernagel et al. 2000) On: food/drink, goods, transport and waste. Self-report. Housing estimated from secondary data (meter readings).	UK households (n=28) in Aberdeen, Scotland Interviews, preliminary questionnaire, a two week diary-recording period. Diary recordings were entered in a spreadsheet EF calculator.	Awareness was raised. Behavior change was not measured.
6	Laakso and Lettenmeier (2016)	Material Input Per unit of Service (MIPS); Household-level Sustainability Transition methodology (HST). On: Housing and nutrition (wk 1), household goods and leisure time activities (wk 2) and mobility and tourism (wk 3). Self-report.	Households (n=5) in Jyväskylä, Finland, Based on first questionnaire material footprints were calculated. Co-creation workshop to develop household-specific visions in roadmaps. 4-week experiment with self-chosen ideas from roadmap. Final future workshop with participants and stakeholders.	Awareness was raised. Footprints were smaller.
7	Lin (2016)	PErsonal CArbon FOotprint Management System (PECAFOMS) on: campus activities, family life, water resource, transport, waste disposal, and waste recycling. Self-report.	Taiwanese high school students (n=66) Quasi-experiment. Two groups: simple footprint calculator 4 times (n=33) vs. PECAFOMS six times (n=33). Pretest and posttest questionnaire on determinants of environmental behavior and behavior.	Awareness was raised. Footprints were smaller for the simple calculator.
8	Lin (2017)	PECAFOMS on: campus activities, family life, water resource, transport use, waste disposal, and waste recycling. Self-report.	Taiwanese students (n=279). Questionnaire on beliefs, attitudes, intentions, personal norms and continuance intention.	Not an effect study.
9	Mallett et al., (2013)	Manipulated carbon feedback on: Transportation, housing, spending habits. Self-report.	US Students (n=152) urban Midwest Computer experiment	Experience of more guilt, and higher willingness to volunteer.
10	Salo et al. (2019)	Baltic Sea Card, Car comparison calculator, Climate Neutral Now, CO_2-beregneren, Ducky, Ilmastodieetti, Klimatkontot, Kolvidur calculator, Min klimatpåverkan (REAP Petit in UK), WWF UK environmental carbon footprint	Evaluation of 10 footprint calculators in Nordic countries on characteristics (opportunities/ limitations). Interviews with six calculator hosts on expectations and experiences.	Not an effect study.
11	Sutcliffe et al. (2008)	Ecological Footprint Analysis (EFA) on: food, energy, transport, house and garden size, waste production and consumer spending. Self-report.	UK households (n=18). Four questionnaires on awareness, attitudes and behavior. After Q2 a mini report with feedback and tips.	Footprints were reduced.
12	West et al. (2016)	REAP Petite footprint calculator	Users in UK (n=28) and Sweden (n=21) Residents meetings and interviews on use of calculator.	Not an effect study.

3.2.1 Studies with positive effects on behavior

Sutcliffe et al. (2008) investigated the effect of an ecological footprint and intentions to change among 18 UK households. Participants completed four questionnaires over a 3-month period, and they were provided a *mini-report* to read between Questionnaires 2 and 3 which linked global overshoot to individuals' lifestyles. In this mini-report each household was provided with their footprint, and with scenarios that included specific impact reductions that could be made by the individuals or the household. In Questionnaire 4 participants were asked whether they had incorporated any changes since the communication of their footprint and production of the report. The 18 households who intended to make reductions to their footprint, responded mainly positively in questionnaire 4 when asked whether they had carried out any or all their intended actions. The researchers concluded to have reached an 100% conversion rate since all participating households took some action to reduce their ecological footprints.

Laakso and Lettenmeier (2016) investigated the effect of material footprint methodology among five Finnish households. In this type of footprint focuses on the use of natural materials and resources for daily behaviors[5]. Their study included calculating material footprints for participating households for three weeks, developing household-specific visions in the form of roadmaps during a workshop, and having participating households conduct experiments for 4 weeks. During the experiments, the researchers made calculations on their effects to the material footprints, as well as observations on how the experiments affected everyday practices of households. After the one-month period of experiments, the households and the project team, together with infrastructure providers, service providers and municipal servants, discussed the experiences and results from the project. This intervention went further than providing people with a number of goals or pledges: guidance was quite comprehensive, and participants met in real-life workshops two times. Participating households aimed at halving their material footprints in their individual roadmaps, but during the one-month experiment period all these reductions were not possible to achieve (like energy renovations on the basis of consulting). However, all household succeeded in dropping their material footprints considerably towards their roadmap targets during the experiment period.

Aichholzer et al. (2012) performed a two-year study in Germany, Austria and Spain among participants (n=222) of several local climate initiatives that used an advanced carbon calculator adapted for regular bimonthly measurements. The calculator was based on four main activities (energy supply, mobility, nutrition, consumption), and the tool provided four major features: *Individual feedback, Comparative feedback over time, Comparative feedback with other groups, Supporting information and learning opportunities*. Around two-thirds of the participants showed a reduced carbon footprint after nearly two years. Individually this group achieved the local targets and the panel as a whole saved about 0.036 tons of CO_2 per person within a two month period. This corresponds to the assumed positive effects of feedback. However, opposed to the improvements, there were also significant increases in CO_2 emissions among the remaining one-third of participants: their emission increased by 24%. In effect, the smaller number with negative trends caused 0.15 tons more CO_2, than the twice as big group with

[5] Material inputs are calculated separately for five resource categories: abiotic raw material, biotic raw material, soil movement in agriculture and forestry, air, and water.

improved balances saved. Although the CO_2 emissions were reduced in total, this triggered a significant rebound on the total emission reduction of the whole group.

Lin (2016) adopted a quasi-experimental approach to estimate the effects of a PErsonal CArbon FOotprint Management System (PECAFOMS) on 66 Taiwanese students. The student-centred PECAFOMS included questions on campus activity, family life, water resource, transport use, waste disposal and waste recycling. The respondents in the test group A (n=33) were asked to use PECAFOMS six times during six months, while respondents in the B group (n=33) were asked to use a simplified form of a calculator (CFC) four times during the first four months. By means of a pretest and posttest participants' carbon reduction and the determinants of environmental behavior were compared. Results show that the carbon footprint system has significant, positive effects on the reduction of their daily self-reported carbon footprint, both at four (30% reduction) and six months (19% reduction compared to the start). In the B group no reduction was found. Furthermore the carbon footprint system significantly improved carbon footprint awareness and perceived behavioral control, and increased behavioral subjective norms. The reduction of respondents' self-reported carbon footprint was significantly correlated to perceived behavioral control, carbon footprint awareness and attitude.

In a follow-up study **Lin (2017)** looked at factors predicting the continued use of this PECAFOMS carbon footprint calculator using a questionnaire among 279 Taiwanese students. It showed that regular users are individuals who have a positive low-carbon attitude, have a higher low-carbon behavioral intention, and (or) perceive stronger low-carbon subjective norm, and who feel satisfied and (or) perceived usefulness.

Gram-Hanssen and Christensen (2012) studied the users a Danish Internet-based carbon calculator called Map my Climate. A total of 220 respondents completed a first survey, and 99 users completed a follow-up questionnaire two weeks later. The first questionnaire included questions on the duration of the website visit, how it had influenced them, attitudes and knowledge about climate change and everyday practices before the visit. The follow-up questionnaire further inquired whether users had actually changed any practices to reduce their carbon footprint or whether they thought they would do so in the future. A majority of respondents indicated that the website had provided them with new knowledge about climate change and CO_2 emissions, encouraged them to do more to reduce the impacts of their lifestyle, and provided new knowledge about personal actions. The researchers concluded that considering the short time that users visited the website and that they were quite knowledgeable and interested beforehand, it was surprising how many of them believed that the visit induced them to change their practices. The follow-up survey painted a somewhat different picture: more than half (58%) recalled only in part or not at all their visit to the website, and for all consumption areas the majority (51–64%) indicated that they had not changed any practices since their visit. However, for heating, electricity, and food more than 20% reported that to some or a high degree that they had changed behaviors after their visit.

Finally, **Mallett et al. (2013)** did not measure actual behavior as a result of a using a carbon footprint calculator, but their experimental research (study 1) showed that US students (n=152) who used a carbon footprint calculator and received

(manipulated) feedback that they had a higher footprint than the average U.S. citizen, experienced more feelings of guilt than participants who received feedback that their footprint was lower than average. Moreover, in a follow-up study 2 participants received feedback on the overall United States' carbon footprint compared to the footprint of other industrialized nations. Participants in the worse-than-peers condition appeared to have a stronger intention to support a pro-environmental group by for example signing a petition or donating money.

3.2.2 Studies without positive effects on behavior

Büchs et al. (2018) examined the effect of personalized information through a longitudinal field experiment (RCT: randomized controlled trail) in which they tested the effectiveness of a *carbon calculator interview* among 218 households in the UK; of which 95 were part of the experimental group and 123 were part of the control group. The interview provided participants in the experimental group with their personal carbon footprint in various domains (space heating, water heating, lightening and electrical appliances, car travel, other surface travel, air travel, and household goods), and with a comparison to UK averages. In a qualitative debriefing interview, participants were taken along several options tailored to their situation through which they could reduce their carbon footprint. Moreover they were asked which options they would consider to adopt. During the two years of the experiment participants in both groups received eight surveys.

The carbon calculator interview was based on three explanations of why personalized information is more effective than general information, namely *creating awareness of consequences*, providing people with information relevant to their situation (*tailoring*) and providing feedback on progress (*behavioral monitoring*). Participants were made aware of the ways in which their behaviors were connected to emissions, as the calculator calculated emissions based on a range of behavioral questions, e.g. whether they take a shower or bath, how far/often they travel by car or train. In addition, since the carbon calculator covered emissions from different behavioral domains, it also showed participants which types of actions would be more effective in reducing their carbon footprint, for instance by highlighting the carbon intensity of flights compared to switching off lights.

The results of the study showed that participation in a carbon calculator interview significantly increased participants' awareness of options to reduce their carbon footprint, as well as their climate change concern. However, the intervention did not result in measurable reductions in residential and travel related energy use. Furthermore, qualitative results within this study supported the finding of the non-effectiveness of this carbon calculator in regard to behavior change, since a majority of the intervention group participants were only willing to undertake changes that did not have a considerable impact on their lifestyle.

Chatterton et al. (2009), found similar results in their qualitative analysis of public attitudes towards the use of carbon calculator tools in relation to making transport decisions. Higher awareness or more knowledge of consequences on its own did not lead to behavior change. The study included 15 focus groups (each of approximately 10 participants) in which participants discussed the carbon impact of daily behaviors (session 1) and hands-on explored existing carbon calculators (session 2). This study in other words focused on discussing the potential of carbon

calculator tools, and did not include measurement of participants' behavior. Despite considerable awareness of climate change as an issue among participants, personal carbon emissions were not found to have much influence on their personal transport choices. Cost (both in time and money), comfort and convenience proved to be more important transport choice determinants.

Hunter et al. (2006) studied the effect of a two week diary study among 28 Scottish households. After the two weeks an ecological footprint summary sheet was provided to householders as part of a follow-up feedback interview. A number of participants expressed surprise at the relative importance of specific categories to the overall household footprint. Most commonly, householders perceived for example waste to be of greater significance than footprint estimates suggested, perhaps because waste was a highly visible issue, being physically weighed by householders as part of diary keeping. This demonstrates, according to the researchers, the potential educational value of a detailed, component-based approach in identifying the most significant (at least in terms of footprint analysis) contributors to household environmental impact.

The study showed that although comparison of household footprints (adjusted to a per person basis) with the 'fair earth share' value did appear to have an initial impact; this did not appear to last and in most cases expressions of resignation and powerlessness followed. Similarly, whilst all householders were generally interested to compare their individual household footprint with the Scottish household average, and normally expressed relief if theirs was lower, this benchmark too appeared to have little impact.

3.2.3 Behavior change techniques

The twelve studies included in our review show that carbon footprint approaches use various behavior change techniques and do not only provide the personal footprint scores. See Table 2 for an overview. Below we describe the most common techniques used.

Table 2. Behavior change techniques used in the twelve studies

	Authors	Behavior change techniques
1	Aichholzer et al. (2012)	Individual feedback (tailoring); Comparative feedback over time (behavioral monitoring); Comparative feedback with others; Supporting information and learning opportunities.
2	Büchs et al. (2018)	Individual feedback (tailoring); Comparative feedback over time (behavioral monitoring); Comparative feedback with others; Goal setting (intentions to change)
3	Chatterton et al. (2009)	Providing environmental information
4	Gram-Hanssen and Christensen (2012)	Individual feedback: quick test (tailoring); Individual feedback: detailed profile (tailoring); Comparative feedback (with IPCC scenarios); Providing environmental information (effect of climate change on different areas of Denmark).
5	Hunter et al. (2006)	Individual feedback (tailoring); Comparative feedback with other groups (Fair earth share); Comparative feedback with others (Scottish average).
6	Laakso and Lettenmeier (2016)	Individual feedback (tailoring); Imagination of future self; Goal-setting to halving material resource use; Comparative feedback over time (behavioral monitoring); Create social environment with other participants and others (social support and social learning).
7	Lin (2016)	Individual feedback (tailoring); Comparative feedback over time (behavioral monitoring);
8	Lin (2017)	NA

	Authors	Behavior change techniques
9	Mallett et al., (2013)	Comparative feedback with others (U.S average); Comparative feedback with others (Industrialized countries).
10	Salo et al. (2019)	Most common techniques as described in their overview article: Individual feedback (tailoring) but be aware of information overload; Comparative feedback with others (neighborhood, country, global level); Goal-setting (pledges or intention setting); Comparative feedback over time (behavioral monitoring); Create social environment with other participants (social support and social learning).
11	Sutcliffe et al. (2008)	Individual feedback (tailoring); Comparative feedback with others (number of globes needed if everyone had the same footprint); Goal-setting (intentions to change) Comparative feedback over time (behavioral monitoring)
12	West et al. (2016)	Individual feedback (tailoring); Comparative feedback with others; Comparative feedback over time (behavioral monitoring); Goal-setting (pledges)

Tailoring: Personalized information

Carbon footprint calculators are founded on the idea that personalized or tailored information encourages people to change their behavior and thus reduces their carbon footprint (e.g. Salo et al., 2019). Studies show that personalized information is indeed more effective than general information, because it improves the applicability to one's situation (Abrahamse et al., 2005; Benders et al., 2006; Büchs et al., 2018; Rietkerk & Menkveld, 2017). If information is relevant to one's situation, information overload can be avoided. Another explanation of why tailored information is more effective than general information, is that it increases the relevance of one's message.

The tailored feedback that people receive can focus on their own behavior or on norms (what others in your group do or think). With regard to their own behavior, showing people how much progress they already made in achieving a goal can encourage people to keep up or intensify desired behaviors (McCalley and Midden, 2002). While this especially applies to behaviors with clearly set goals, for instance weight loss or fitness targets, it can be regarded as relevant for pro-environmental behavior as well, if participants have a general interest in reducing or maintaining a 'reasonably sized' carbon footprint[6]. In this case a goal can for example be set in relation to reducing one's original footprint, e.g. reduce my footprint by 10%. Or in relation to the 'group': the emission of an average person or household in one's country, e.g. not exceeding the average emission.

Social comparison

Many social psychological studies show that social comparison is a strong incentive for behavior: when people see other people (especially people that are relevant to them) act in a specific way they are more inclined to act similarly. In the Focus theory of normative conduct these so-called descriptive norms are identified as a motivator for behavior (Cialdini and Kallgren, 1990). In social marketing the term social contagion is used for a similar phenomenon: the process by which consumers influence each other to buy or use a product (Langley et al., 2012). Contagion is on the one hand about social aspects, such as which group they belong to and with whom they interact, and on the other hand about characteristics of the product, such as how often and for how long people should continue to use a product. Social contagion, like the descriptive norm, is about the visible behavior of others and copying it.

[6] There are many studies on how to communicate on CO_2 emissions, as this concept is quite abstract for most people - comparable to counting calories in weight loss.

Personal goal setting

Salo et al. (2019) evaluated ten different footprint calculators in the Nordic countries (see Table 1), and described their opportunities and limitations. They found that calculators often include pledges. A pledge is a form of personal goal setting. For instance, pledges in the REAP Petite UK calculator include the following (Salo et al., 2019; **West et al., 2016**[7]): "Replace all my lights and appliances with energy efficient ones, when needed"; "Walk or cycle to my local shops rather than drive to the supermarket"; or "Use eBay and freecycle to do more of my shopping". These goals or pledges can even be more effective when they are formulated in an 'if-then' way. For example 'if I need a new light bulb, then I will buy LED' or 'if I need groceries then I will walk to my local shops'. These so-called implementation intentions – simple contextual plans to break habits and guide consumer choice – are known to being able to help motivated individuals (Beattie, 2012; Gollwitzer, 1999).

In more general terms, studies show that defining clear and concrete goals (goal formation) can help people in changing their behavior. Setting ambitious but feasible goals can be motivating for some people, but for others graded activity (small steps that lead to an overall bigger goal) can be more applicable. Having people gradually taking steps towards a sustainable lifestyle that fits their current situation could be useful for both groups. To maintain behavior change over time, it is important to keep monitoring one's goals. Reviewing and reinforcing are essential elements.

Comparison over time and repeated use

Furthermore, Salo et al. (2019) describe that calculators they reviewed included features for repeated use. We also see that carbon footprint calculators differ in the length of the footprint period and how often they provide feedback. Some provide a footprint for one year, and provide this footprint only once, while other calculators - often in the form of apps- provide information and feedback more often (bi-monthly, monthly, weekly or even daily). Abrahamse et al. (2005) described in their overview study of the effect of environmental behavior change interventions that personalized information was most effective the more frequently it was given. Some carbon calculators indeed have features for repeated use and aim to provide support in the long run. Such features include the personal history of taken actions and footprint results, pledges, and social features.

User engagement however often proves to be difficult. Salo et al. (2019) showed that while many calculators have features that allow users to return to their results to track activities and progress over time, the challenge of engaging people to use a calculator more than once was highlighted by many of their interviewees. The study by Salo et al (2019) showed that number of repeated users of four different calculators appeared to be low. Only when users receive active notifications (like SMS, email or online messages), and are explicitly reminded engagement can be increased.

[7] West et al. (2016) developed the REAP Petite footprint calculator and tested its usability with a group of users in the UK and Sweden. How many users were included in this study and what they were asked was however not well documented in this paper. Based on their experiences they advised to enable comparison of footprints, and to monitor and evaluate tool use and effects.

Several studies from the realm of household energy reduction examined long-term effectiveness (after one or two years) of providing tailored information or feedback on the reduction of home energy use. While one study showed an increased effect over time (Hirst and Grady, 1983), several others concluded that behavioral effects had disappeared in the long-term (Allcott and Rogers, 2014; Darby, 2008; Hargreaves et al., 2013; Van Dam et al., 2010). The main explanation that these studies provided for the limited long-term effects of personalized information is that the novelty of the monitoring equipment and/or intervention was wearing off over time while contextual and habitual factors regained importance in shaping behavior. A recent study by TNO among nearly 50.000 Dutch households on the effect of improving regular personalized information on household energy use, with for example historic and comparative feedback, even showed no initial effect (Paradies et al., 2020).

Providing information on effect of behavior and footprint

An assumption of carbon footprint calculators is that the information provided by the calculators would lead to a change in consumption patterns, mainly through raising awareness and knowledge (e.g. Salo et al. 2019). The studies in our review subscribe that carbon footprint calculators indeed can lead to a higher awareness. A higher awareness does however not automatically lead to behavior change. Norm activation theory (Schwartz, 1977) states several conditions that need to be in place so that people can act on personal norms, which are expectations that people hold for themselves (see Figure 4). A personal norm can for instance be an environmental norm to reduce one's carbon footprint. One of these conditions is the "awareness of consequences" of one's actions. While this usually refers to consequences for the person, for instance in terms of rewards or sanctions, it has been broadly applied in the literature to argue that the provision of personalized information or feedback can make people more aware of the ways in which their actions affect energy use or carbon emissions (Abrahamse et al., 2005; Benders et al., 2006; McCalley and Midden, 2002). The underlying assumption is that people are often unaware of the connection between their actions and energy use/emissions because in many ways the latter remain "invisible" (Burgess and Nye, 2008).

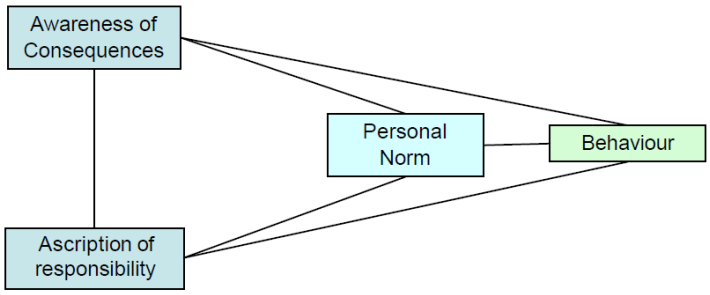

Figure 4. Schwartz' Norm Activation theory

3.2.4 Role of other behavior related factors

The role of motivation

Devoting time and effort to calculate one's footprint is a voluntary exercise. It is likely that in particular people with an environmental mind-set are potential users of footprint calculators (Gram-Hanssen and Christensen, 2012; Salo et al., 2019). All studies we reviewed therefore consist of motivated people: if a person does not find the environmental issues problematic or a priority in their life, the calculator may not be relevant to them. In a study among Taiwanese grad students, Lin (2017) identified the predictors of carbon footprint calculator continuance intention. Regular carbon calculator users proved indeed to be individuals with a positive low-carbon attitude, a higher low-carbon behavior intention, and (or) stronger low-carbon social norm perception. An interview study among carbon calculator developers showed that altogether the number of users was moderate (Salo et al., 2019). The highest number was approximately 20,000 per year on average and the range was from 1000 to 122,000 users during the entire lifetime of the calculator. In other words, thus far the number of carbon calculator users is limited.

When people lack motivation to use a footprint calculator, it will be hard to engage them in using one. An explanation can be found in Self-Determination Theory which identifies a belief in one's own freedom to choose as a key requirement for sustained motivation (Deci & Ryan, 2012). When people get the feeling they have to do specific things and their autonomy is threatened, reactance can occur – i.e. rebellion against undertaking the new behavior (see Figure 5). On the other hand, when people have the feeling they are in control and are free to choose, they are more likely to change their behavior (e.g. described in Rietkerk & Menkveld, 2017).

Figure 5. Self-determination theory by Deci and Ryan (2012)

On a side note, also competence (experience of mastery) and relatedness (will to interact with others) could be utilized to enhance people's personal growth goals towards psychological health and well-being which is in some ways related to leading a sustainable lifestyle.

Removing barriers

The carbon footprint calculator studies show that people have difficulty changing their environmental behavior and are mainly willing to undertake changes that do not have a considerable impact on their lifestyle. Taking away implementation barriers could lead to progress. Various studies identify barriers that limit the implementation of pro-environmental behavior in people's daily life. For example

how to fit pro-environmental behavior in everyday practices, the cost of these behaviors, or the effect on comfort and convenience. People differ in how much these barriers are perceived as actual barriers, and barriers also differ per behavior type (for example retrofitting one's home is different from daily food choices for family dinner). Graded activity helps people in setting steps that fit their actual situation. Challenges could be used to slowly build up to more impactful behavior.

3.3 Main insights

Based on the papers we come to the following main insights.

1. There is little high quality research
There has been little high quality research into the effects of carbon footprint calculators, except from the study by Büchs et al. (2018). The quality of the studies is generally low (see also Salo et al., 2019): there is a limited number and diversity of participants, the data is mainly self-report (only two studies made use of energy bills), and there is a lack of a long term follow-up. In addition only two of the seven studies that measured effects on behavior made use of a control group. The results of our review therefore need to be viewed in that perspective: drawing strong conclusions on the best approach is not possible.

2. Carbon footprint calculators can lead to changes in awareness and behavior
The results on behavior change are mixed. The reviewed studies show that carbon footprint calculators can lead to a higher awareness and more knowledge, but this does not automatically lead to individual behavior changes and lower footprints.

The carbon footprint approaches that did affect people's behavior and footprint included several factors leading to success. For example, there was intensive contact between researchers and participants and in between participants (Laakso and Lettenmeier, 2016), people received very specific and comprehensive feedback on what they could do reduce their footprint (Laakso and Lettenmeier, 2016; Sutcliffe et al., 2008), and people were reminded of participating in reducing their footprint during a longer period of time (Aichholzer et al., 2012; Lin, 2017). The studies by Sutcliff et al. (2008) and Laakso and Lettenmeier (2016) included specific goal setting and evaluation of progress. In other words, the approaches were more than merely filling in a footprint calculator.

3. But carbon footprint calculators are sometimes also ineffective
With regard to the studies that did not find an effect on behavior, it was not always clear why there was no effect. This was also partly the case in the study by Aichholzer et al. (2012) that found a positive behavioral effect among part of their respondents, but a negative behavioral effect among another group. Büchs et al. (2019) conclude that their study confirmed results from previous studies that showed that personalized information interventions tend not to be effective in encouraging low carbon behavior changes in the long term, especially not for behaviors that people perceive as 'difficult' to undertake. It also confirmed a range of previous studies which demonstrated attitude-behavior gaps, again especially for 'difficult'-to-change behaviors such as air travel. Results from other studies furthermore suggest it is unrealistic to expect carbon calculators to support behavioral changes in 'difficult', high carbon areas as participants were only

prepared to make ‘small’, convenient changes in response to carbon feedback programs. The greater the CO_2 reduction potential of actions, the smaller households’ willingness to implement them. Reasons for this reluctance is that these measures will have the biggest impact on their lifestyle.

4. Only a small group of people is interested in calculating their footprint
Carbon footprint calculators are often designed to support a rational reflection of lifestyle and activities from an environmental perspective. They are therefore used by an (environmentally) motivated minority, and studies include mainly motivated respondents. Even within this motivated group a using carbon calculator by itself does not lead behavior changes.

5. Taking away implementation barriers can lead to progress
Various studies identify barriers that limit the implementation of pro-environmental behavior in people’s daily life. For example how to fit pro-environmental behavior in everyday practices, their cost, the effect on comfort and convenience. Graded activity could help people in setting steps that fit their actual situation. Challenges could be used to slowly build up to more impactful behavior.

6 Personal goals can be perceived as out of reach
We found an interesting general observation of carbon footprint calculators by Franz and Papyrakis (2011, p.391) that “even when the most environmentally friendly options are adopted, for the majority of available indices, one still exceeds the planet’s biocapacity levels. The absence of options to fully offset one’s environmental impacts implicitly suggests that there is no truly sustainable level of consumption at current population levels, even under the most prudent consumer choices.” The interview study by Salo et al. (2018) among developers of carbon calculators showed a similar result: One interviewee highlighted that even if the user actively takes the suggested actions, the total contribution is small due to the high emissions of basic necessities of housing, food and personal transport in affluent societies. Therefore, it is difficult to achieve the sustainable footprint, and this can lead to frustration or discouragement by its users. This should be taken into account by setting realistic goals for users.

7. Carbon footprint calculators need a content update
With regard to the carbon footprint calculators themselves, we saw that the calculators in most studies included categories on household energy, mobility, food, and consumer products. Some studies also included the garden and waste recycling, or the use of a second home. We noticed that the footprint calculators in the studies do not include online services, such as streaming services, e-mail, etc. In the last decades energy use for online services such a streaming, saving data in the cloud, and block chain emerged (Jones, 2018).[8] Furthermore, pro-environmental behaviors regarding green citizenship or activism are not part of most carbon calculators (see also Annex A).

4 Studies on health interventions

As the number of studies into the effects of carbon calculators is limited, we turned to the field of health interventions to get insight into how the calculators could be improved to get better results in (difficult) behavior change. When we describe “health behaviors” this is about recurring daily or weekly behaviors such as exercise or healthy eating choices; it is for instance not about mental health or vaccination. When we talk about “interventions” this can be anything from text messages, to help sheets, to a smart phone game. In this field there has been put much effort into investigating the effect of various behavioral change techniques and the effect of combinations of these techniques. Furthermore, we found various approaches comparable with the personalized feedback that carbon footprint calculators provide. For example, we found eHealth apps that give users daily diet and exercise feedback to stimulate healthy diet choices or encourage exercise behavior. In this chapter we describe a number of relevant health studies aimed at behavior change and the lessons we can draw.

It should be noted that the health domain is different from that of sustainability in the sense that improving one’s health provides relatively short term benefits for the individual, such as weight loss or feeling energetic, while progress in sustainable behavior has more unclear, long term benefits for humanity. This will likely influence the level of motivation to which people are willing to change and be able to sustain to change their behavior. However, we believe that for both health and sustainable behavior the same techniques could be utilized.

4.1 Combinations of behavior change techniques are most effective

In our introduction in Chapter 1 we referred to the COM-B model by Michie et al. (2011). This model originally focused on health related behaviors. As described this model recognizes that to change behavior three groups of factors have to be in order: people have to be capable, motivated, and opportunities should be presented to them to engage in the behavior. The COM-B model is founded on several studies and taxonomies of the effect of interventions.

To find out which mechanisms make an intervention effective Abraham and Michie (2008) developed a taxonomy of 26 behavior change techniques (BCTs) with standardized definitions that were linked to theory[9]; see Table 3. The BCTs are clustered in three categories: motivation enhancing, planning and preparation and goals striving and persistence. In the right column of Table 3 the techniques are defined; they vary from for example providing information (BCT no. 1), to providing feedback (13) or using prompts (17).

[9] Since 2008 the taxonomy has been updated, and other taxonomies have been developed. We start here at the beginning and describe how the taxonomies have developed below.

Table 3. Definitions of 26 behavior change techniques and illustrative theoretical frameworks, per category

Category	Technique (Theoretical Framework)	Definition
Motivation-enhancing	1. Provide information about behavior-health link. (IMB)	General information about behavioral risk, e.g., susceptibility to poor health outcomes or mortality risk in relation to the behavior.
Motivation-enhancing	2. Provide information on consequences (TRA, TPB, SCogT, IMB)	Information about the benefits and costs of action or inaction, focusing on what will happen if the person does/ does not perform the behavior.
Motivation-enhancing	3 Provide information about others' approval (TRA, TPB, IMB)	Information about what others' think about the person's behavior and whether others will approve or disapprove of any proposed behavior change.
Motivation-enhancing	4. Prompt intention formation (TRA, TPB, SCogT, IMB)	Encouraging the person to decide to act or set a general goal e.g., to make a behavioral resolution such as "I will take more exercise next week".
Planning and preparation	5. Prompt barrier identification (SCogT)	Identify barriers to performing the behavior and plan ways of overcoming them.
Goal striving and persistence	6. Provide general encouragement (SCogT)	Praising or rewarding the person for effort or performance without this being contingent on specified behaviors or standards of performance.
Planning and preparation	7. Set graded tasks (SCogT)	Set easy tasks, and increase difficulty until target behavior is performed.
Planning and preparation	8. Provide instruction (SCogT)	Telling the person how to perform a behavior and/ or preparatory behaviors.
Planning and preparation	9. Model/ demonstrate the behavior (SCogT)	An expert shows the person how to correctly perform a behavior e.g., in class or on video**.**
Planning and preparation	10. Prompt specific goal setting (CT)	Involves detailed planning of what the person will do including a definition of the behavior specifying frequency, intensity or duration as well as specification of at least one context, i.e., where, when, how or with whom.
Goal striving and persistence	11. Prompt review of behavioral goals (CT)	Review and/or reconsideration of previously set goals or intentions.
Goal striving and persistence	12. Prompt self-monitoring of behavior (CT)	The person is asked to keep a record of specified behavior/s (e.g., in a diary).
Goal striving and persistence	13. Provide feedback on performance (CT)	Providing data about recorded behavior or evaluating performance in relation to a set standard or others' performance. Person received feedback.
Goal striving and persistence	14. Provide contingent rewards (OC)	Praise, encouragement or material rewards that are be explicitly linked to the achievement of specified behaviors.
Goal striving and persistence	15. Teach to use prompts/ cues (OC)	Teach the person to identify environmental cues which can be used to remind them to perform a behavior, including times of day, contexts or elements of contexts.
Planning and preparation	16. Agree behavioral contract (OC)	Agreement (e.g., signing) of a contract specifying behavior to be performed so that there is a written record of the person's resolution witnessed by another.
Goal striving and persistence	17. Prompt practice (OC)	Prompt the person to rehearse and repeat the behavior or preparatory behaviors.
Goal striving and persistence	18. Use follow up prompts	Contacting the person again after the main part of the intervention is complete.
Planning and preparation	19. Provide opportunities for social comparison (SCompT)	Facilitate observation of non-expert others' performance e.g., in a group class or using video or case study.
Planning and preparation	20. Plan social support/ social change (social support theories)	Prompting consideration of how others' could change their behavior to offer the person help or (instrumental) social support, including "buddy" systems – and/or providing social support.

Category	Technique (Theoretical Framework)	Definition
Planning and preparation	21. Prompt identification as role model	Indicating how the person may be an example to others and influencing their behavior or providing an opportunity for the person to set a good example.
Goal striving and persistence	22. Prompt self-talk	Encourage use self-instruction and self-encouragement (aloud or silently) to support action.
Goal striving and persistence	23. Relapse prevention (Relapse Prevention Therapy)	Following initial change, help identify situations likely to result in re-adopting risk behaviors or failure to maintain new behaviors and help the person plan to avoid or manage these situations.
Goal striving and persistence	24. Stress management (stress theories)	May involve a variety of specific techniques (e.g., progressive relaxation) which do not target the behavior but seek to reduce anxiety and stress.
Motivation-enhancing	25. Motivational interviewing	Prompting the person to provide self-motivating statements and evaluations of their own behavior to minimize resistance to change.
Planning and preparation	26. Time management	Helping the person make time for the behavior (e.g., to fit it into a daily schedule).

In 2009 Michie et al. examined the effectiveness of physical activity and healthy eating interventions focused on adults using the taxonomy described before. They identified 122 evaluations of interventions and found that such interventions are on average effective with effect sizes of 0.32 and 0.31 for physical activity and healthy eating interventions, respectively. These are small-to-medium effect sizes (Cohen, 1992) in the typical range for psychological interventions.

In addition Michie et al. (2009) found that interventions combining self-monitoring with one or more of four other hypothesized self-regulation techniques, namely, prompting intention formation or goal setting, specifying goals in relation to particular contextualized actions, providing feedback on performance and reviewing previously-set goals were significantly more effective than interventions not including self-monitoring and one other self-regulatory technique (pooled effect sizes for healthy eating: 0.54 versus 0.24; physical activity: 0.38 vs. 0.27; all interventions {healthy eating and physical activity}: 0.42 vs. 0.26).

Moreover, their results showed that the behavioral target and many design characteristics (duration, person delivering the intervention, delivery format [e.g., individual versus group], setting [e.g., workplace or community settings], use of multiple sessions, time to follow up, target population did not differ between effective and ineffective interventions. Finally, the number of behavior change techniques included did not increase effectiveness.

Michie et al. (2009) concluded that their analyses offered clear support for including self-monitoring of behavior as well as prompting intention formation or goal setting, specifying goals in relation to particular contextualized actions, providing feedback on performance and reviewing previously-set goals in interventions designed to promote healthy eating and physical activity.

A reanalysis of the data from Michie et al. (2009) using a different methodology was performed by Dusseldorp et al. (2014). They found the strongest synergistic effect with motivation-enhancing BCTs (see Table 3). Of particular interest was the fact that interventions that included *Prompt intention formation* (BCT no. 4), but **did not use** *Provide information about behavior– health link* (1), showed the lowest mean

effect size (g=0.24) in this category. This finding seems to suggest that those interventions that aim to motivate change, without addressing the perceived need for changing (e.g., personal susceptibility), are actually worse off than the average intervention effect (i.e., g=0.31). For carbon calculators this implies that the need for change should be included and clear for its users.

Across the three behavior change categories, three results were striking. First, *Prompt review of behavioral goals* (11) appeared to be an important predictor of intervention success. The 19 interventions that included this BCT showed a relatively high mean effect size (g=0.40). These 19 interventions also used several other techniques, so it cannot be concluded that interventions using only this technique will be successful. In case of footprint calculators this means that it would be beneficial to have users set a goal or intention and send messages to remind them to review their goal and progress.

Second, interventions that used *Provide information about behavior– health link* (1) **with** *Provide information on the consequences* (2) **and** *Use follow-up prompts* (18), but **without** *Prompt review of behavioral goals* (11), were **most effective** (g= 0.46). This result suggests that interventions that combine motivation-enhancing techniques with a technique explicitly provoking persistence, such as the use of follow-up prompts, are promising. Apparently, this combination is a useful alternative for the successful technique *Prompt review of behavioral goals* (11). Although, *Use follow-up prompts* (18) and *Prompt review of behavioral goals* (11) may be effective via a different mechanism, essentially, they both may offer important control strategies. For carbon calculators this alternative approach would imply that users would need motivating information in combination with follow-up contact, without referring to goals or intentions.

Third, those interventions that used *Provide feedback on performance* (13) as a technique, **without** using *Provide instruction* (8)*, Provide information on consequences* (2), and *Prompt review of behavioral goals* (11), were **least effective** (g= 0.05). Of these latter three, the lack of *Provide instruction* (8) seemed important, because those interventions that used the combination of *Provide feedback on performance* (13) **and** *Provide instruction* (8), **without** the use of the other two BCTs, showed an effect size similar to the average (g=0.31). These results suggest that providing feedback on performance may have a counterproductive effect when not providing clear instruction of the ‘desired’ behavior. This means that in footprint calculators, clear instructions on how to change behavior are essential. The question might be what this looks like, how detailed this needs to be.

In 2013 Michie et al. developed a more elaborate taxonomy of 93 BCTs clustered into 16 groups. The main reason to improve their own 2008 taxonomy was to increase its reach: it proved that only a few research groups worked with and on improving the taxonomy, and that it was mainly developed for particular behavioral domains (e.g. physical activity, smoking, or safer sex). Regarding their new ‘BCT Taxonomy v1’ Michie et al. (2013) concluded that it lays the foundation for the reliable and systematic specification of behavior change interventions. These BCT taxonomies are however developed as a means to categorize intervention content, and ‘evidence of “efficacy” or “effectiveness” is not part of the definition of BCTs. As Kok et al. (2016) describe these taxonomies contain effective behavior change

methods (techniques), but they also contain ineffective methods, and may even contain counter-effective methods. This also showed from studies into combinations of BCTs as described before. For the purpose of intervention design Kok et al. (2016) therefore developed a taxonomy that include additional aspects of the dynamics of behavior change. They state that for a behavior change method to be effective it:

1) must target a determinant that predicts behavior (e.g., guided practice is an effective method to enhance self-efficacy or to train skills, but not to change subjective norms);
2) must be able to change that determinant (e.g., if a behavior is exceptionally easy to perform, targeting self-efficacy will not yield behavior change);
3) must be translated into a practical application in a way that preserves the parameters for effectiveness and fits with the target population, culture, and context .

In sum, the studies in this paragraph show that specific combinations of behavioral change techniques have proven to have most effect in changing health behaviors. Especially interventions that combine motivation-enhancing techniques with a technique explicitly provoking persistence, such as the use of follow-up prompts, are promising. Moreover, providing feedback on performance may have a counterproductive effect when not providing clear instruction of the 'desired' behavior. In addition interventions should target changeable factors that predict behavior in a practical and fitting way. These are useful insights to apply to the design of pro-environmental behavior interventions including carbon footprint calculators.

4.2 Nudging to improve health behaviors

A different meta-analysis worth mentioning is recent one by Cadario and Chandon (2020) on nudges to change eating habits. Nudges are defined by Thaler and Sunstein (2008, p.6) as "any aspect of the choice architecture that alters people's behavior in a predictable way (1) without forbidding any options or (2) significantly changing their economic incentives. Putting fruit at eye level counts as a nudge; banning junk food does not." Some of the abovementioned behavioral change techniques can be labeled as nudges, but not all.

Cadario and Chandon (2020) gathered 299 effect sizes from 96 studies reported in 90 papers. They examined the effectiveness in field settings of seven healthy eating nudges, classified according to whether they are:

1) cognitively oriented, such as "descriptive nutritional labeling", "evaluative nutritional labeling", or "visibility enhancements";
2) affectively oriented, such as "hedonic enhancements or "healthy eating calls"; or
3) behaviorally oriented, such as "convenience enhancements" or "size enhancements".

Effect sizes increased as the focus of the nudges shifts from cognition (d=0.12,−64kcal/day) to affect (d=0.24, −129 kcal/day) to behavior (d=0.39, −209 kcal/day); see Figure 6. Moreover, this overview showed that interventions are more effective at reducing unhealthy eating than increasing healthy eating or reducing total eating.

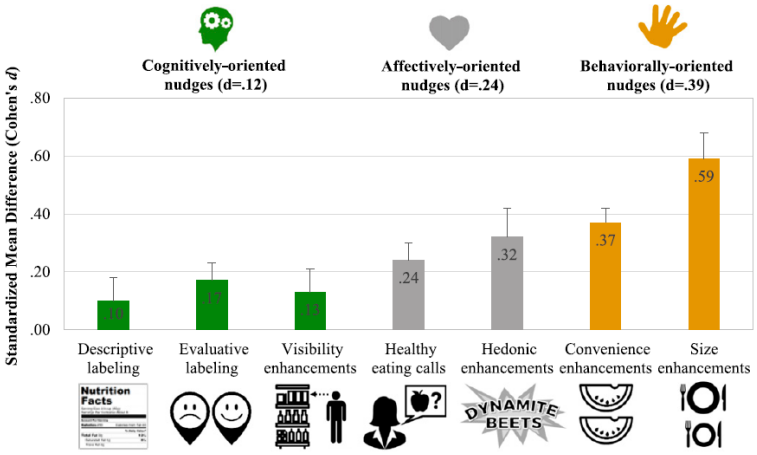

Figure 6. Effect sizes by nudge type. Source: Cadario and Chandon (2020)

Regarding pro-environmental behavior we learn that nudges can have a small to medium effect, and that especially behaviorally-oriented nudges can have most effect. What 'smaller portion sizes' and 'making unhealthier options less convenient to select or consume' are for (un)healthy eating, could for instance be 'smaller meat and cheese portions' or 'making unsustainable options less convenient to consume' for pro-environmental behavior. Although nudges are about choice architecture and not so much part of a carbon calculator, these insights about designing the context are also of value for encouraging pro-environmental behavior.

4.3 Health equivalents to the carbon footprint calculator

As carbon footprint calculators are often available online or in the form of apps (see Appendix A), we in addition looked at meta-studies on the effects of internet-based or eHealth interventions.

App stores offer many different health related apps. Rivera et al. (2016) reviewed 393 mobile apps for weight management. These apps included features like self-monitoring (35%), physical activity support (28%), weight assessment (25%), healthy eating support (23%), goal-setting (21%), motivational strategies (7%), social support (5%), and personalized feedback (2%). Similar to carbon calculator apps, commercial mobile apps for weight loss/management have mostly not undergone scientific testing; only 0.8% (3/393) underwent scientific evaluation. The results of the evaluation of these three apps (My Fitness Pal, Lost It!, and Fitbit) were not described in the review and the original research was not referenced.

Next to these health apps that have not been tested, there also are overview studies of eHealth interventions that were indeed thoroughly investigated. Webb et al. (2010) examined the effectiveness of 85 Internet-based interventions and found that the two BCTs that were associated with the greatest changes in health behavior were *Stress management* (24) and *General communication skills training* (included in a list of 40 BCTs instead of 26 in Table 3). Both techniques influence behavior change indirectly via mechanisms such as facilitating problem-solving, promoting self-efficacy, or diminishing the impact of stressors that may prevent behavior change. However, Webb et al. (2010) described that relatively few interventions employed these techniques, so the findings should be treated with

caution. Modeling, relapse prevention/coping planning, facilitating social comparison, goal setting, action planning, and provision of feedback on performance all had smaller effects. Moreover, the effectiveness of Internet-based interventions was enhanced by the use of additional methods of communicating with participants, especially the use of short message service (SMS), or text, messages. This also showed in a meta-analysis on 75 RCT studies on mobile technology-based health interventions for health care consumers (Free et al., 2013). Multifaceted mobile technology text messaging interventions increased the adherence to antiretroviral medication in a low-income setting and increased smoking cessation in a high-income setting. The text messages were multifaceted in the sense that they encouraged patients to maintain contact, to monitor, and to respond to medication issues. Finally, Webb et al. (2010) found that intervention effectiveness was larger when more BCTs were included. Note that this is opposite to the findings by Michie et al. (2009).

In another meta-analysis of 15 RCT studies on personalized eHealth interventions aimed at overweight and obese adults, Lau et al. (2020) found that on average the respondents in the experimental groups lost more weight and became more healthy on a number of indicators. They identified the following crucial design elements: utilizing a combination of tailored content and customized feedback with human feedback, usage of theoretical basis, short message service, device, reminder, self-monitoring, goal setting and synchronous communication, and the duration preferred ranges from 12 to 14 weeks.

In sum, also for these eHealth interventions it showed that combinations of behavior change techniques proved to be most successful in improving health related behavior.

4.4 Behavior change over time

As described, behavior change interventions can be effective in supporting individuals in achieving behavior change. However, Kwasnicka et al. (2016) described in a systematic review of behavior theories that behavior change maintenance is rarely addressed. As pro-environmental behaviors are for the long-term, this is a very relevant issue.

Kwasnicka et al. (2016) identified 100 behavior theories, and five overarching themes representing theoretical explanations for behavior change maintenance emerged. Theoretical explanations of behavior change maintenance focused on the differential nature and role of motives, self-regulation, resources (psychological and physical), habits, and environmental and social influences from initiation to maintenance (see box 1).

It showed that individuals need at least one sustained motivator to maintain behavior; these may include behavior enjoyment, satisfaction with behavioral outcomes, self-determination or an experience of behavioral congruence with beliefs and values, all of which often develop after initiating a new behavior. It is likely that individuals start behavior change attempts at times when their motivation is at the highest and opportunity costs are low. As motivation decreases and opportunity costs increase over time, the need for self-regulatory effort is increased

in order to ensure that the new behavior continues despite less than optimal conditions. We would describe this as a crucial phase, as putting in an effort to change behavior under these circumstances is really hard. In a different study Kwasnicka et al. (2017) showed that tailored and person-centered approaches are effective to help people maintain a healthy weight. This could be an effective approach also in the situation of pro-environmental behavior. Delivering such personalized interventions efficiently at scale will be a challenge, but not be impossible.

In the next step, with repeated performance of a new behavior, the need for conscious self-regulation decreases and behavior becomes easier and habitual, which in turn increases the chance that it will be maintained.

Finally Kwasnicka et al. (2016) describe the importance of context. Context is not so much part of the BCT taxonomies that do not include all techniques that could be of importance (Dusseldorp et al., 2014). Behavior occurs within an physical and social context, with such influences serving to either facilitate or hinder behavior change maintenance. Studies on smoking for example show the effect of social networks on smoking cessation and relapse among adults (Blok et al., 2017; Frank, 2020). Blok et al. (2017) revealed that respondents with the largest proportion of smokers in their social network were less likely to quit smoking and more likely to experience a relapse. Smoking cessation and relapse were most strongly associated with the proportion of smokers among household members and friends. The proportion of smokers in family outside the household was not related to smoking cessation and smoking relapse. Also regarding weight loss maintenance several studies have shown that effect of social support (Kwasnicka et al. (2017). People are more likely to maintain their weight loss if their environment is supportive and stable. As with the initiation of behavior change, stable contexts make behavior and habits easier to sustain. Thus, ecological factors are important for both behavior initiation and maintenance.

To conclude, behavior change over time can be achieved by including or hooking into different motivations such as enjoyment or other personal values; and by in the end creating new habits so little motivation is needed. Achieving this will be a challenge since it requires personalized guidance. In addition providing people with resources and creating a behavior stimulating context are import factors.

Box 1. Guidance for intervention developers: target five maintenance processes

(1) Helping individuals to maintain positive behavior change maintenance **motives**, emphasizing positive outcomes of a new health behavior, providing behavioral options which are enjoyable, inspiring individuals to redefine themselves in line with new healthy lifestyle principles.
(2) Facilitating behavior **self-regulation**; for instance through self-monitoring behavior and helping individuals to develop effective strategies to overcome behavioral barriers and to prevent **relapse**.
(3) Facilitating **habit development** and maintenance for positive health behavior changes; for instance by reshaping the environment and making healthy options salient and by cuing individuals towards healthy behaviors.
(4) Providing individuals with **resources** that are needed to successfully maintain a new health behavior. Resources can be physical (e.g., sport facilities, health products) or psychological (e.g., self-regulation training, mindfulness and relaxation methods).
(5) **Reshaping the environment** at individual, social and community levels. Providing social support and introducing social changes that are in line with positive health behavior change maintenance.

4.5 Main insights for carbon footprint calculators

In short we learned the following lessons and how they can be applied to the practice of carbon footprint calculators.

1. Combinations of specific behavior change techniques are promising
Interventions that combine motivation-enhancing techniques with a technique explicitly provoking persistence, such as the use of follow-up prompts, are promising. Finding out what motivates users of carbon footprint calculators, and customize prompts and feedback on this motivation may be an effective approach. As described, it is likely that in particular people with an environmental mind-set are potential users of the calculators, but also within this group motivations may vary between for instance, saving the planet or preserving biodiversity, or making sure one's (grand)children have a good life in the future, or religious reasons (stewardship). Text messaging (SMS) proved to be an effective way of prompting people to change their behavior, if they include multiple aspects of the change process (maintaining contact, monitoring and responding to current health issues).

2. Provide concrete feedback on desired behavior
Providing feedback on performance may have a counterproductive effect when not providing instructions of the desired behavior. It is important to clearly add what a person or household can do after providing their carbon footprint, and to ensure that this is feasible. It is yet unclear how much detail is needed to genuinely help people, but starting with an easier behavior in combination with feedback an reinforcement seems most promising. Next steps would be to advance to more difficult behaviors (with concrete feedback and reinforcement).

3. Target changeable factors
In addition to the first two insights, interventions should target factors that predict behavior and it should be possible to change that factor. Furthermore interventions must be translated into a practical application in a way that they remain effective and fits with the target population, culture, and context.

4. Design the physical and social context
Behavior change techniques are often focused on individual behavior change, but both the physical and social context affect behavior change too. Behaviorally-oriented nudges that focus on changing the physical context have proved to have a medium sized effect: for example adjusting portion sizes or focusing or facilitating the convenient choice.

Several studies show that people are more likely to maintain their behavior if it is embedded in their social structures. For example, a supportive and stable social environment, or that the desired behavior is normal within their group – in which case a new behavior can lead to social approval. Studies provide evidence for network-based interventions, particularly including household members and friends. In case of carbon footprint calculators or pro-environmental interventions, adding social aspects (e.g. engaging friends and families) or social approaches (including Carbon conversations, 'Klimaatgesprekken' in Dutch, or groups on social media that include social peer groups) could lead to larger effects. Social norms in favor of pro-environmental behavior are also important in this sense.

5. Focus on behavior maintenance instead of short term change
People need at least one sustained motivator to maintain behavior; these may include behavior enjoyment, satisfaction with behavioral outcomes, self-determination or an experience of behavioral congruence with beliefs and values. Pro-environmental behaviors are also founded by various motivations and it is important to have insight in which motivations are relevant to a person and when. These motivations can be reinforced by emphasizing positive outcomes of a new behavior, providing behavioral options which are enjoyable, or by inspiring individuals to redefine themselves in line with their new green lifestyle principles. Only a subgroup of people will be motivated by contributing to mitigating climate change.

6. Enhance motivation by short term gains
If people lack any motivation, other pathways than a strong focus on a carbon calculator will be more effective in changing behavior. Especially short time goals that are based on other values and motivations than acting pro-environmentally. Similar to improving healthy lifestyle choices, pro-environmental behaviors are about long term gains that (often) ask for short time investments that can be perceived as a loss. A focus on short term gains could be a promising avenue for this particular group (and also for more intrinsically motivated people).

7. Tune in to the different phases of behavior change
People start behavior change attempts at times when their motivation is at the highest and opportunity costs are low. Carbon footprint calculators should therefore focus on a good start with intensive engagement at the beginning. For example, at the start instant and applicable feedback should be provided, and learning should start immediately. In addition, graded activity could help people in setting steps that

fit their actual situation. Challenges could be used to slowly build up to more impactful behavior.

As over time motivation decreases and opportunity costs increase, the need for self-regulatory effort is increased in order to ensure that the new behavior continues despite less than optimal conditions. At this low point, tailored and person-centered approaches may be effective: in other words reaching out to a user to stimulate their motivation while taking into account individual differences.

With repeated performance of a new behavior, the need for conscious self-regulation decreases and behavior becomes habitual, which in turn increases the chance that it will be maintained. The use of a carbon footprint calculator becomes less appropriate at this time.

5 Conclusions and way forward

5.1 Conclusions

In this report we aimed at answering two questions:

1 What do previous studies show about the effect of carbon footprint calculators on awareness and behavior?
2 Are there ways to improve footprint calculators to become more effective in changing behavior?

Effects of carbon footprint calculators on behavior vary

The literature on the effects of carbon footprint calculators on pro-environmental behavior is limited and it shows mixed results. The available studies show that carbon footprint calculators are effective in increasing knowledge and awareness, however providing people with only personalized information seems insufficient to encourage people to act more pro-environmentally. Successful approaches include, next to a carbon footprint calculator, intensive guidance or frequent contact with and among participants, clear goal setting and reinforcement of progress. But as there is a lack of high quality studies, drawing strong conclusions on the best approach is not possible.

App stores already provide a broad variety of carbon footprint apps, but whether they are effective is unknown, since there is a lack of scientific testing. We noticed a similar situation within the field of health apps for mobile phones: a large selection of apps but few are studied (e.g. Rivera et al., 2016). However, the fact that most people are only willing to make pro-environmental changes that do not have a considerable impact on their lifestyle, implies that it is unlikely that these apps cause behavior change when no additional support is provided.

Carbon footprint calculators can benefit from including additional behavior change techniques

The literature on health interventions shows the potential of combining different behavior change techniques to change behavior. Especially interventions that combine motivation-enhancing techniques with a technique explicitly provoking persistence, such as the use of follow-up prompts, are promising. To maintain behavior change individuals need at least one sustained motivator; these may include behavior enjoyment, satisfaction with behavioral outcomes, self-determination or an experience of behavioral congruence with beliefs and values, all of which often develop after initiating a new behavior. For pro-environmental behavior this could for example be enjoyment of a simpler life, being motivated by self-sufficiency or valuing nature and the environment. That new behaviors are turned into habits is an important next step, but probably asks for tailored and person-centered approaches that are time intensive to provide.

Not all people will be motivated to use a carbon footprint calculator. For these people other interventions are needed in order to reduce their carbon footprint, for instance an approach that is directed at other motivations, values, or benefits such as saving money, improving health or self-improvement. Opportunities should be facilitated by stimulating changes in for example product and service availability (including infrastructures) that enable a low carbon lifestyle. Similar to improving

healthy lifestyle choices, pro-environmental behaviors are about long term gains that (often) ask for short time investments that people can perceive as a loss. A focus on short term gains could be a promising avenue for this particular (large) group, especially in combination with other values and motivations than acting pro-environmentally. Short term goals could for instance be improving one's health because of using a bicycle or eating less meat, enlarging one's family time because of working at home, or a credit gaining system within an intervention (e.g. collect credits to plant a tree).

Taking all lessons into account, we first should note again the difference between health and pro-environmental behavior. It is often noted by researchers in the field of environmental behavior that if people are already unwilling or unable to change behaviors that would lead to a healthier life, how should any progress be expected on a topic that seems even less personal? Motivation to change really is a weak spot: many people do not feel like doing high impact pro-environmental behaviors as it has a huge impact their personal lifestyle. Having said that, we think that successes from health interventions can be applied to pro-environmental behavior to find out if change can be realized within a group of people that are motivated but also outside this group progress can be made. In addition, when in the (near) future people will be motivated in new ways, for example in the form of taxation of CO_2, it is essential to have resources in place and be ready to support people.

Our overview shows that merely providing carbon footprint outcomes will not lead to people lowering their footprints, but when providing these footprints as part of a larger approach in which a combination of techniques is used, and the social and physical environment are in some way aligned this could lead to positive effects. Having people gradually taking steps towards a sustainable lifestyle (graded activity) that fits their actual situation could be a promising approach. Offering (personalized) information is a fundamental part of the process of people considering changing their behavior. We think offering it on a daily basis in the form of an app, with an additional cap or target could be fruitful if in combination with a larger approach as described.

5.2 Way forward

5.2.1 Practical application

Use carbon footprint calculators as part of a national communication plan
We recommend exploring how a footprint calculator can be part of a national communication plan focused on citizen engagement. Benefits of adding a footprint calculator are that people receive personalized information about their own impact, that they get to see an integral picture of what causes CO_2 emissions, and that they receive personalized information on how they can lower their footprint. It should be noted that it would be wise to not only provide tips that focus on individual action (such as buying solar panels), but also on collective actions (such as voting and becoming active in local initiatives), to avoid feelings of helplessness. This fits the suggestion by Gram-Hansen et al. (2012) to design internet based carbon calculators that actively engage users in collective actions instead of primarily presenting individualistic interventions. The acknowledgement that to make

environmental behavior easier we need changes in policies can help both citizens as policy makers.

Integrate carbon footprint calculators in a broader intervention
For the best results we recommend to integrate carbon footprint calculators with broader interventions, such as programs that combine motivation-enhancing with provoking persistence and adding social aspects. An example is the Carbon Conversations approach in which a volunteer coach guides a group of about ten people to talk about their impact and how to take action. Another example is the Eco Team Program (see Staats et al., 2004) that used a combination of information, feedback, and social interaction in a group—the EcoTeam— to focus on the environmental consequences of their household behavior. By adding other support elements, the knowledge and awareness gained by using the footprint calculator can be transformed into behavior change.

Adding goal setting elements to such an intervention could be fruitful; for instance goal systems theory (Kruglanski et al., 2002) that focuses on the questions of how to achieve what and why. The two important constructs in this theory are goals (representations of desired end-states) and goal-means (behaviors that can help one accomplish a goal). Kruglanski et al (2002) in addition define goals as a hierarchy of three layers: ultimate goals (personal values, identity), sub goals and means. Furthermore focusing on short term gains and on how to improve, could motivate many people regardless whether they hold pro-environmental values or not.

5.2.2 Research

We see interesting avenues for further research in the following directions:

A large scale study into the effects of footprint calculators
Our review on carbon calculator studies showed that there is a lack of good quality studies into the actual effect of carbon footprint calculators on behavior. The study by Büchs et al. (2018) is the mere exception. We think it would be useful to do a large scale RCT with a test and control group, with a representative sample of society. Ideally, multiple carbon footprint approaches (with more or less behavior change techniques) would be tested in multiple test groups. Behavior should not only be measured by self-report but in combination with more objective data (for example energy use data and geodemographic data on travelling). Furthermore it is important to do this kind of study over a longer period of time, in order to investigate behavior change and possible maintenance over time.

Research the effects of the daily or weekly use of footprint apps
The effect of a regular (daily or weekly) use of footprint apps has not yet been researched. We believe these apps do have potential because reminders by an app can create daily interaction and elongate the period in which people are engaged with the subject of reducing their carbon footprint. Reducing one’s footprint is not a subject which is top of mind in daily life without notifications or reminders. Furthermore, adding a carbon cap or target to people’s personal emissions could steer them towards actually lowering their footprint. Since people are inclined to perceive simple and easy, low impact behavior as a fair (enough) contribution (Thøgersen and Crompton, 2009), and have the tendency to rely on doing one thing (single action bias) to reduce a potential risk of an issue (Weber, 1997), the broader

scope of a carbon footprint combined with a clear goal could diminish these tendencies. This approach would also reduce rebound effects, as reducing CO_2 emission in one area (e.g. saving on energy use to warm your house) while spending the money you saved in another (e.g. buying electronics) will immediately show that CO_2 use has not been reduced[10].

Research the effects of the use of a footprint calculator on support for environmental policies
Next to designing interventions aimed at individual behavior there are other ways to encourage pro-environmental behavior, including implementing government policies that encourage, restrict or tax certain behavioral options. To successfully implement these policies they need sufficient social support, as when there is a complete lack of support for specific policies compliance will be problem. The other way around, as we found in the literature, people find it difficult to behave sustainably even when they are motivated. For some this leads to feelings of helplessness. New policies could help people in behaving more sustainably, for example by taxing CO_2 that would lead to higher prices of products with high emissions (for example use of fossil fueled cars or meat and dairy products). Since there has not been any research on the effect of carbon footprint calculators on policy support (such as signing a petition or contacting a politician), we suggest this as an avenue for further research.

Another argument to focus on policies is that it provides a clearer view on the situation. As described in the introduction, the Dutch media regularly post articles on an supposedly dichotomy between focusing on what people do individually and what the role of the system (including the government) should be. Some conclude that the focus on individual action, and accordingly measuring each other up on their greenness, takes away pressure on where it really should be: on governments taking up stricter regulations for industries and companies, and therefore also for citizens (for example in the form of higher prices and less choice of goods). This dichotomy can be removed by informing people about what they *can* do as part of “the system”.

Research on the perception and effects of a personal carbon budget
A follow-up step after calculating carbon footprints could be to set a limit on the size of the footprint. The idea of a personal or household carbon limit (that could be used in a personal carbon trading scheme) has been proposed but has not yet been properly worked out. The studies on footprint calculators show that for inhabitants of highly developed countries like the Netherlands it is quite hard to reach a truly sustainable level of consumption, even under the most prudent consumer choices. This means that setting a limit could lead to merely frustration and discouragement. It could be interesting to investigate people how they feel about the concept and implications of the personal carbon budget. An attempt was made by Capstick, & Lewis (2009). In their study people were asked how they would feel and what they would do when such a personal carbon would be implemented.

Explore the integration of carbon footprint with a “happiness calculator”
Footprint calculators only appeal to small percentage of the Dutch citizens. According to market research bureau Motivaction (2019) around 22% of Dutch

[10] Provided that this level of detail is available in the calculator to detect these changes.

inhabitants is interested in their personal contribution to sustainability. Another avenue to explore is to integrate the carbon footprint calculator with a so-called happiness calculator. This is another type of motivation (personal growth) which would appeal to another group (Motivaction, 2019). This calculator would test how happy or satisfied with life you are, and what you could do to increase this. This idea is based on the premises that 1) people think they need to buy goods or products to be happy, which is a misconception, a human bias, and 2) things that do make us happy do not emit a lot of carbon, examples are spending time with friends, and working on mental habits. The things that make us happy and in addition have a low carbon footprint could be marketed with the help of this calculator.

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A Overview of footprint calculators

We made an overview of various carbon calculator apps available online and in different app stores. These apps are not included in this report, since there are no (public) evaluations of the effects available. We included this overview here to give an idea of the current offer of online carbon calculators. This list includes a number of calculators, but we acknowledge that we probably did not find all calculators available.

	Name	Domain	Set-up	Type
1	beCon (be conscious) www.becon.live	Mobility	CO_2 footprint based on survey and GPS. Daily footprint Set weekly budget for NL Social platform Notifications	App
2	Buycott www.buycott.com	Food Goods	Barcode scanner. Insight in GMO, fair trade, animal testing, plastic pollution of products Option to notify companies via social media or mail	App
3	Capture: my carbon footprint www.thecapture.club	Mobility Air travel Food	US CO_2 footprint based on survey and GPS. Monthly budget Offsetting	App
4	Climate coach4U www.climatecoach4u.nl	Clothing Food Goods In home Energy Mobility Holidays Finance	Footprint calculated based on survey. Yearly footprint Comparison with footprint Netherlands and world. Challenges in 8 categories.	App
5	Dierenwelzijns Check www.dierenwelzijnsCheck.nl	Food	Climate and animal welfare score of meat, fish, dairy and meat substitutes. Thumbs up or down	Website
6	Doconomy https://doconomy.com	Finance	Swedish credit card with a monthly limit based on CO_2 emission. The Åland Index calculates the carbon impact of every single transaction Users receive tips, including carbon offsetting	Credit card
7	Ecoview https://lifeview.azurewebsites.net	Food Mobility Consumption In home	CO_2 footprint based on financial data Monthly footprint	Website
8	Evocco www.evocco.com	Food	Irish shopping assistant to make sustainable choice in supermarket. Upload receipts and receive feedback (tips).	App
9	Eevie www.eevie.io	In home Mobility Food Consumption	CO_2 footprint based on survey Small changes every day. Community Tips for new habits Goal setting: yearly goal to work on daily basis Notifications	App
10	For good www.forgood.eco	Mobility Food Energy	CO_2 footprint based on survey and GPS tracking. Footprint per week/day Challenges for companies. Social platform Notifications and emails	App
11	Good on you. Ethical fashion app. (before: Rank a brand) https://goodonyou.eco	Clothing and shoes	Sustainability score per brand	App

	Name	Domain	Set-up	Type
12	Greenswapp www.greenswapp.com	Food	Online groceries: CO_2 score of each product Tips for alternatives Offsetting	App
13	Joro https://joro.tech	Mobility Food In home	US. Survey and credit card purchases Challenges offsetting Tips	App
14	Mijn impact https://mijnimpact.nl/pages/impact-test	Goods Food In home Driving Air travel Clothing	CO_2 footprint based on survey Yearly footprint. Feedback: number of globes. Combined with web shop	Website
15	Mijn verborgen impact http://impact.babetteporcelijn.com	Goods Food Mobility In home	CO_2 footprint based on survey. Yearly footprint. Feedback: number of globes	Website
16	Milieu centraal CO_2 calculator https://advies-op-maat.milieucentraal.nl/aom/?module=CO_2-voetafdruk	Car and public transport Air travel Energy in home Food Clothing	CO_2 footprint based on survey Yearly footprint Tips (option via e-mail)	Website
16	My little carbon footprint hwww.plasticsoupfoundation.org/psf-in-actie/my-little-plastic-footprint/	Plastic	Select and participate in actions to reduce plastic use Notifications	App
17	Onetonnefuture (Vattenfall) https://onetonnefuture.com	In home Mobility Food Consumption	CO_2 footprint based on long or short survey Yearly footprint Goal setting Social comparison Challenges: shopping offsetting	App
18	Questionmark www.thequestionmark.org	Food	Barcode scanner. Database with environmental and health score of products in the supermarket. Receive direct feedback that helps in making choices in the supermarket	App
19	Voedselafdruk www.voedingscentrum.nl/nl.aspx	Food	CO_2 food footprint based on survey Carbon and water footprint per day. Challenge for one week Email reminders	Website
20	Warmd https://fredjul.github.io/Warmd	In home Mobility Food Goods and services	French carbon footprint calculator based on a survey. Yearly footprint Tips Individual and global approach: voting, activism, number of children	App