Faculty 11: Human- and Health Sciences

Economic evaluation of digital public health

A cumulative dissertation

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by

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Abstract

Digitalization has become relevant in the health sector since the development of the internet and smartphones. Accordingly, interest in digital healthcare technologies has been increasing. An area that still warrants further investigation is the use of digital technologies for disease prevention and health promotion at the population level. This has been associated with the term digital public health (DiPH). Prevention effectively mitigates the problem of potentially costly diseases; however, it is unclear whether there are specific points to consider in the evaluation of whether DiPH interventions are cost saving or, at least, cost effective. While health care significantly contributes to greenhouse gas emissions, it is unclear whether DiPH interventions are facilitating the reduction of or increase in greenhouse gases.

Therefore, this thesis is guided by three research questions (RQs). RQ1 explores what should be considered in the economic evaluation of DiPH interventions. RQ2 reviews the health economic evidence on preventive DiPHs intervention using decision analytical modeling. RQ3 explores the evidence of CO_2 emissions resulting from digitalization in the public health sector. These three RQs are investigated within four modules (M).

The first two modules address specific issues related to the health economic evaluation of DiPH in book chapters on evaluation (M1) and sustainable financing of DiPH (M2). The issues include the need to account for high technology dynamics, for the potentially low marginal cost of covering additional users, or for identifying new ways of including carbon footprint into economic analysis. Given the importance of modeling in the economic assessment of DiPH, M3 presents the results of a systematized review of health economic evaluations using decision analytic modelling of DiPH. It shows, for example, that the types of preventive DiPH interventions that are covered by economic evaluations as well as their results and methodological quality are very heterogeneous. A systematic review (M4) of the calculations

of virtual care (as one field of digitalization in healthcare) carbon footprints shows that digital technologies may sometimes help reduce carbon emissions. However, existing calculations lack methodological rigor.

This thesis demonstrates that DiPH represent an important and partially specific area of health economic investigation. To exemplify how specific issues may be addressed, an exemplary economic evaluation of a preventive digital intervention is outlined which includes, for example, a DiPH-specific sensitivity analysis. Decision-makers should be able to add an environmental perspective to the established concepts of economic evaluation. Therefore, an extension of the CHEERS checklist to include carbon footprint into health economic evaluation is outlined, which needs to be further developed. Future research should consider this when designing economic evaluations of DiPH.

A. Synopsis

After an introduction into the context of this thesis, chapter two provides an overview of its methods, chapter three summarizes its results and chapter four provides a critical discussion. Chapter five draws short conclusions on the economic evaluation of digital public health (DiPH) interventions.

A.1. Introduction

The limited resources of the public sector, including the public health sector, make it necessary to make critical decisions related to financial resources. Within the field of health economics, there are methods of economic evaluation that compare the costs and benefits of different interventions to promote the allocation of scarce resources to the most efficient ones. Technological advancements have led to innovations such as computers, the internet, and smartphones, which also marked the beginning of digitalization for the public sector. Various novel technologies have been introduced. In addition to improving the effectiveness of treatments for diseases that have already emerged, a DiPH intervention may facilitate the transition from prevention to cure (Odone et al. 2019). While telephones and messaging (for example, in doctors' surgeries) were also used in the past, various software and hardware technologies have emerged to further improve health interventions. Thus, the digitalization of the healthcare system may offer new opportunities for developing effective and cost-efficient health interventions. However, based on these technologies, a large number of new interventions have been developed, and the paradigm of evidence-based decision-making necessitates their investigation and validation. This also relates to their cost-effectiveness.

In the following section, digital public health will be defined and examples will be provided. Subsequently, the basic economic evaluation methods will be introduced. Finally, the research questions of this thesis will be stated.

A.1.1. Digital public health

There are various frameworks for defining DiPH according to public health functions or digital health functions.

DiPH may be defined based on vertical essential public health functions, such as health protection, health promotion, disease prevention, health care, preparedness for public health, and emergencies (World Health Organization 2018). This encompasses the prevention and treatment of diseases. Another framework characterizes digital technologies by function. The National Institute for Health and Care Excellence evidence standards framework for digital health and care technologies describes 10 functions of digital health technologies: (1) system services with no measurable patient outcomes; (2-4) providing the platform for the collection of information on conditions or general lifestyle, maintenance of health diaries, and communication; and (5-10) facilitating healthy behavioral changes, self-management of specific conditions, treatment, and active monitoring (e.g. using wearables) and calculating the impact on the treatment and diagnoses of specified conditions (Unsworth et al. 2021). While this framework is somewhat more specific in terms of intervention, it covers both preventive health services and disease treatment.

Wienert et al. (2022) combined the public health function framework (World Health Organization 2018), National Institute for Health and Care Excellence evidence standards framework for digital health and care technologies (Unsworth et al. 2021), and the user-centered approach (Wright 2021) to derive the definition that a DiPH "Intervention addresses at least one essential public health function through digital means. Applying a framework for functional classification and stratification categorizes its interaction level with the user. The developmental process of a digital public health intervention includes the user perspective by applying participatory methods to support its effectiveness and implementation with the goal to achieve a population health impact." (Wienert et al. 2022).

These definitions include treatment, especially in the context of the vertical essential public health functions within healthcare. The treatment of diseases that have already developed is important; however, the prevention of diseases is critical. The Department of Health and Social Care (2018) asserts that prevention is better than cure. This is also based on the assumption that public health interventions can help saving cost in the health sector (Masters et al. 2017). While it is undisputed that this does not mean that the focus should solely be on the evaluation of prevention, previous studies on digitalization in healthcare have reported on other concepts that focus on treatment of individuals, such as electronic health (Sanyal et al. 2018), mobile health (Ghani et al. 2020), or digital health (Jiang et al. 2019) interventions.

The digitalization of public health may provide several benefits including empowering patients and people and help to be in the center; and facilitating more efficient, safer, and cheaper healthcare management (Odone et al. 2019). For the first potential benefit of facilitating the transition from cure to prevention, there are reasons to take a closer look at the evaluation of preventive digital health services.

Therefore, this thesis will follow the definition of Zeeb et al. (2020) that focuses on the population level and prevention as well as health promotion (Zeeb et al. 2020).

A.1.2. Digital public health case studies

In the past, technological interventions were predominantly focused on information and telecommunication; however, there are new technologies that can be used in healthcare. Old interventions were likely to be delivered via telephone. Before the introduction of smartphones, web- and internet-based applications were dominant. With the widespread use of smartphones, there are more possibilities for digital interventions.

DiPH interventions can vary widely. In Europe, examples include chatbots or dashboards that provide information about COVID-19; teleconsultations aimed at reducing the incidence of COVID-19; digital tools for interaction with the health system among health care providers or civitzens; software and web-based applications to promote mental health; or mobile applications to treat childhood obesity (Wong et al. 2022).

If the focus is placed on preventive health interventions, the goals may include promoting physical activity or weight loss. For promoting physical activity, several interventions use smartphone apps (e.g., Silva et al. 2020), wearables (e.g., Ringeval et al. 2020), or both (e.g., Gal et al. 2018, Laranjo et al. 2021). While these reviews partly included randomized controlled trials (RCTs) that targeted patient groups and may be useful for the treatment of diseases, smartphone apps and activity trackers can also be used to help individuals lose weight. For example, Antoun et al. (2022) reviewed RCTs of interventions that used smartphone apps for weight loss in at least one arm. The included interventions were partly complemented by behavioral interventions, activity trackers, or apps alone.

A.1.3. Economic Evaluation

Given the limited resources in health systems, opportunity costs should be considered for any investment decision on public health interventions: funds used for the treatment of a given disease cannot be invested in other interventions. For an investment decision, the costs and health outcomes of different interventions should thus be compared. One method to do so is the umbrella term economic evaluation which includes various types of analyses.

While cost analysis only investigates costs (assuming effects are equal), the other types of economic evaluation compare costs and consequences. All types of analysis assess and value costs in monetary units. Cost–effectiveness analysis (CEA) measures consequences as a single effect and valuates them in natural units; cost–utility analysis (CUA) can measure consequences as single or multiple effects and valuate them in a generic outcome measure like quality-adjusted health years (QALYs) or disability-adjusted life years (DALYs), measures that combine length and quality of life; and cost–benefit analysis (CBA) measures consequences as single or multiple effects but valuates them in monetary units (Drummond et al. 2015). It should be noted that different definitions exist. For example, Weinstein et al. (1996) used CEA as an umbrella term for CEA and CUA.

As mentioned above, the forms of evaluation can be distinguished by their outcomes. For the CEA of a preventive DiPH, a single outcome may be case prevented, kg weight loss, or life years gained. CUA allows combining different outcomes effecting length and quality of life (e.g. increased quality of life due to alleviated obesity and lower mortality from diabetes and coronary heart disease following a digital weight loss intervention).

Economic evaluations can be based on the results of a single trial or the synthesis of different sources of evidence through decision-analytical modeling. For economic evaluations, the advantages of decision modeling include the opportunity to synthesize all relevant evidence, consider all relevant comparators, use appropriate time horizons, and integrate probabilistic uncertainty analysis (Briggs et al. 2006). Therefore, economic evaluations using decision analytic modeling may be appropriate because:

(1) rapid technological development may require other study designs rather than potentially time-consuming RCTs, and modeling allows the synthesis of different evidence in one modeling study.
(2) depending on the setting, provisions for other digital interventions in the existing health systems are unclear. Model-based economic evaluation allows the inclusion of various digital and non-digital interventions as comparators.
(3) preventive DiPH intervention might have present costs and long-term health benefits and cost savings that require long analytical time horizons, which are very expensive

for long-term and follow-up trials. Also, DiPH intervention can cause long-term costs when updates are necessary.

(4) The opportunity to include uncertainty analyses is important because only effectiveness studies with small sample sizes may be available or assumptions may need to be made to include relevant comparators for which no evidence from RCTs is available.

If a decision makers intend to include economic evidence in their decisions, their critical assessment and appraisal are necessary. This is also because the choice of the research question, perspective, or time horizon adopted may have an impact on the result of the economic evaluation.

The EQUATOR Network provides guidelines for reporting health research that aims to improve the scientific publication's clarity, completeness, and transparency (Simera et al. 2009). For the health sciences, there are standardized reporting guidelines for the considerations to be made for specific study types. The Consolidated Health Economic Evaluation Reporting Standards (CHEERS) 2022 consist of 28 items that address the title, introduction, methods, results, discussion, funding, and conflict of interests. Originally, these 24-item standards were published simultaneously in 10 journals in 2013 (Husereau et al. 2013). These standards have been recently updated and simultaneously published in 14 journals (e.g. Husereau et al. 2022).

Apart from primary studies, decision-makers can also draw on evidence from systematic reviews (or other forms of review). In these reviews, it is equally important to assess methodological transparency. One standard which can be used for this purpose is the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) (Page et al. 2021). This 27-item checklist guides authors on what they should consider in rating the transparency of systematic reviews (Page et al. 2021).

A.1.4. Environmental evaluation

With the aim of reducing greenhouse gas emissions (GHG), a further decision criterion could be to include the emission of greenhouse gases caused by an intervention. One method to do so is carbon footprint calculation.

There are three main standards for carbon footprint calculation standards (Bathia 2011, PAS 2050 2011, European Committee for Standardization 2018). The carbon footprint of a product can be defined as the "sum of GHG emissions […] expressed as CO2e equivalents and based on life cycle assessment." (European Committee for Standardization 2018) According to this definition, various greenhouse gases with different impacts will be measured in a unified value. Life cycle assessment (LCA) examines the environmental impacts of all phases of a product. This is to prevent environmental effects from being shifted to other life cycle stages and thus influencing the result (Bjørn et al. 2018). In the context of DiPH, a wearable could cause emissions during its production, use and recycling. While life cycle assessment can also examine other environmental effects, the carbon footprint is limited to the impact category of climate change (European Committee for Standardization 2018).

Basically, life cycle assessment is a four-step process (Hauschild 2018): First, it starts with goal and scope definition. Second, information on physical flows (e.g., input of resources and output of emissions) is collected in inventory analysis. Third, the impact assessment translates the information of the life cycle inventory to impacts on the environment. Fourth, the interpretation of results.

Another approach is to use environmental-extended input-output (EEIO) table, which describes "how much emissions or resources are used for each unit of production on a sector" (Mattila 2018). Based on intervention costs and the EEIO, environmental impact can be calculated.

A.1.5. Objectives / Research Questions

Sections A.1.1 and A.1.2. outlined the specific characteristics of DiPH and Section A.1.3 highlighted the rationale and methods of economic evaluations. CHEERS provides a reference on the aspects that should be taken into account during economic evaluations and can influence the results. DiPH may have special features, such as long-term costs due to the need for frequent updates, rapid development, or long-term effects of preventive DiPH interventions. This leads to the first research question (RQ).

RQ1: What should be considered in the economic evaluation of DiPH interventions?

Based on the aforementioned considerations, there is the question of what has been considered in previous economic evaluations. As mentioned above, DiPH can support the transition from prevention to cure (Odone et al. 2019). Furthermore, Zeeb et al. (2020) stated that prevention and health promotion can be the focus of DiPH. Taking health economics into consideration, there is a need to compare interventions and the reasons for considering model-based economic evaluations. This leads to RQ2, with a focus on primary prevention and health promotion, as well as decision analytical modeling.

RQ2: What is the health economic evidence for preventive DiPH intervention using decision analytical modeling?

In addition to the limited financial resources for the public or health sectors, also the global capacity to absorb GHG is limited, while the health system contributes to GHG emissions.

It can be assumed that DiPH help mitigate climate emissions when people can have access to interventions independent of location; However, DiPH interventions may require additional resources for their technological infrastructure. Therefore, a method for assessing DiPH interventions in terms of environmental factors is needed. One approach to addressing this is assessing CF. Given there are different standards for estimating CF, alongside with the evidence assessment, a consolidated assessment standard needs to be developed. This raises the third research question

RQ3: What is the evidence on CO_2 emissions resulting from digitalization in the public health sector?

Research questions 1–3 are addressed by four publications called Modules 1–4 (M1–4). The next chapter will describe the methods (A.2) and synthesis of results (A.3). Section A.4 discusses the general findings, limitations, and implications. Regarding the implications for further research, the results for RQ1-3 will be used to draw implications for modeling a DiPH case study. Additionally, the results for RQ1 and RQ3 will be the basis for conceptualizing the integration of economic and environmental evaluations in the future.

A.2. Methods of this thesis

Based on the context of cumulative doctoral theses, this thesis consists of four modules (Ms). In this chapter, the references for the modules are initially provided, followed by the detailed methods related to the research questions.

- **M1** Lange, O.; Boskamp, P.; Brannath, W.; De Santes, K.; Müllmann, S.; Rogowski, W.; Rothgang, H.: Evaluation of Digital Public Health Interventions. In: Pigeot, I.; Zeeb, H.; Schultz, T.; Schütz, B.; Maass, L. (Eds.): Digital Public Health - Interdisciplinary perspectives [Handbook planned with Springer Nature, Cham, Switzerland] [Status: Accepted]
- **M2:** Lange, O., Rogowski, W.: EPHO8: Assuring sustainable organisational structures and financing in digital public health. In: Pigeot, I.; Zeeb, H.; Schultz, T.; Schütz, B.; Maass, L. (Eds.): Digital Public Health: Interdisciplinary perspectives [Handbook planned with Springer Nature, Cham, Switzerland] [Status: Open peer review completed, reviewer recommended acceptance]
- **M3:** Lange, O.: Decision-analytic health economic evaluation of preventive digital public health interventions: A systematized review. Re-submission under review in: BMC Health Service Research [Earlier version available as preprint]
- **M4:** Lange, O.; Plath, J.; Dziggel, T.; Karpa, D.; Keil, M.; Becker, T.; Rogowski, W.: A transparency checklist for carbon footprint calculations applied within a systematic review of virtual care interventions. International Journal of Environmental Research and Public Health 2022 (19): 12- 7474

The order of M1-4 is not chronological but following the logics of the research questions. Accordingly, the methods for economic evaluation are examined more broadly (M1), followed by a more precise assessment of what should be considered in an economic evaluation (M2). There are reasons for conducting model-based economic evaluation of DiPH; however, the current evidence based on this economic method is unknown. Therefore, the next step is to assess the evidence on model-based economic evaluations of DiPH interventions (M3). M2 also suggests that broader perspectives on DiPH should be considered; further work on this topic is prepared by assessing the environmental effects of carbon footprints within a systematic review with particular reference to methodological transparency (M4).

The structure of the following sections is oriented at the framework of Grant et al. (2009), which compares various types of reviews. The purpose of this framework is to provide an overview of the common review types to prevent the misapplication of terms that have become more common with the expanded evidence-based practice (Grant et al. 2009). The various types of systematic reviews were distinguished using the SALSA framework for the domains of search, appraisal, synthesis, and analysis. This framework of Grant et al. (2009) was chosen because each module has a component dedicated to the assessment of the review types. In the subsequent section, the modules are discussed; their aims and classification and the SALSA framework (search, appraisal, synthesis & analysis) are discussed, where applicable.

A.2.1. Methods of module 1 – Evaluation of DiPH

M1 and M2 will be published as book chapters, entitled “Evaluation” and “Essential Public Health Operation 8: Assuring sustainable organizational structures and financing” respectively, in the book entitled “Digital Public Health – Interdisciplinary Perspectives”.

The “Evaluation” chapter (which corresponds with M1) is divided into subsections entitled “Evaluation of effectiveness” and “Evaluation of cost–effectiveness.” While various authors were involved in the study, this part of the dissertation mainly constitutes the conception and development of the chapter and the sub-chapter "Cost–effectiveness." The subsequent section only describes the method for the sub-chapter "Cost–effectiveness." However, the sub-chapter

"Effectiveness" is also related to the results of this dissertation, as any economic evaluation requires evidence of effectiveness.

The aim of M1 is to provide an overview of the current evidence and methods for evaluating cost–effectiveness. M1 can be classified as a literature review as it provides an "examination of recent or current literature" (Grant et al. 2009) and includes a narrative evidence synthesis.

In particular, the existing studies in the field of DiPH were, on the one hand, retrieved from the M3 search (see A.2.3.) and, on the other hand, from another search strategy modified by adding terms related to CBA and return-on-investment (ROI) studies that was applied to PubMed in August 2022. The search was extended by reference tracking. However, there was no systematic critical appraisal of these studies. The synthesis and analyses were conducted using four cases. Using established concepts of economic evaluation, the cases of (1) individuals' private decisions, (2) coverage decisions in public health using CEA and CUA, (3) coverage decisions in public health using CBA, and (4) companies' investment decisions in occupational health were examined. Each of these cases was reported in terms of the appropriate method and illustrated by studies already conducted in the field of DiPH.

A.2.2. Methods of module 2 – Sustainable financing of DiPH

While M1 describes the different approaches to assessing the cost–effectiveness of DiPH, M2 focuses on the reasons for conducting economic evaluations (especially CEA and CUA) of preventive DiPH interventions. Therefore, M2 systematically investigates what should be considered when conducting an economic evaluation of DiPH. This will be published as a chapter entitled "Essential Public Health Operation 8: Assuring sustainable organizational structures and financing," in the book entitled "Digital Public Health – Interdisciplinary perspectives". The title reflects the placement of this chapter in the context of other essential public health operations. This chapter highlights that methods to increase efficiency is expected to promote sustainable financing.

Based on the report by Grant et al. (2009), M2 can be subsumed under the term “critical review,” as it goes beyond mere description and seeks to identify the conceptual contributions.

The research started with a collection of papers that provide guidance on how to economically evaluate digital healthcare and public health. The sources for these studies are diverse. The basis is the extensive search of the systematic reviews related to M3 (for search details, see Box 1). The titles and abstracts of the studies were screened, and all studies that addressed digital health and reported on methodological features of its evaluation were selected. In addition, further studies were added through search alerts, reference tracking, and manual searches.

There was no formal quality assessment of the included studies. All study types were included. For synthesis, this module combines studies that provide guidelines for the (economic) evaluation of digital health services, as well as the economic evaluation of public health and prevention interventions. Also, established public health and prevention frameworks for economic evaluation (e.g. Haddix et al. 2002, Weatherly et al. 2009) were included. Considering that prevention is an important focus for DiPH, these concepts were combined with the specificities of digital health.

Based on this collection of papers, information on specific aspects of the economic evaluation of DiPH were extracted, following the structure provided by the items of the CHEERS (Husereau et al. 2022). One example is the CHEERS item #8 perspective: If one of the studies stated what should be considered in selecting a perspective or what perspective should be selected, this information was extracted. For the selection of studies, the focus was on recent studies, since, for example, the investigation of telemedicine was already discussed at the turn of the 2000s. However, digital interventions have changed a lot due to the internet and smartphones.

Based on the extracted findings on digital health and public health guidance, the findings were synthesized narratively. The CHEERS items were used. For cases where there were no special features, the headings were combined. Furthermore, suggestions on how to include environmental perspectives in a health economic evaluation were discussed.

A.2.3. Methods of module 3 – Health economic evidence of preventive DiPH

The aim of M3, “Health economic evaluation of preventive digital public health interventions using decision-analytic modeling: a systematized review,” was to investigate RQ2 and perform an extensive search to collect data on the economic evaluation of existing DiPH interventions. While there are existing reviews of digital interventions that treat a disease or condition (e.g. Sanyal et al. 2018), the focus of this study was on primary prevention and health promotion.

Following the classification framework of Grant et al. (2009), the method was a systematized search including a comprehensive search, quality assessment, tabular evidence synthesis, and addressing the limitations of methodology.

To answer the question of what the health economic evidence of preventive DiPH intervention using decision analytical modeling is, it was necessary to develop a comprehensive search strategy (see Textbox 1). Economic evaluations could be included in the search based on titles, as CHEERS item #1 requires the title of an economic evaluation to state "economic evaluation" or the respective type of analysis (e.g. "cost–effectiveness") in the title. However, the question was how to identify preventive DiPH interventions. Since an exploratory search hardly yielded results for the term "digital public health,” the search was expanded to incorporate technologies. Therefore, the search strategy was modified to retrieve studies on all technologies (e.g. web-based, smartphone) and combined with the term “economic evaluation.” However, this included several interventions directed at people who already had a disease. These studies had to be sorted out during the screening process.

("app"[Title/Abstract] OR "apps"[Title/Abstract] OR "smartphone"[Title/Abstract] OR "mobile phone"[Title/Abstract] OR "Smartwatch"[Title/Abstract] OR "cellphone"[Title/Abstract] OR "internet"[Title/Abstract] OR "online"[Title/Abstract] OR "website"[Title/Abstract] OR "web-based" OR "fitness tracker"[Title/Abstract] OR "fitnesstracker"[Title/Abstract] OR "acceleromet*"[Title/Abstract] OR "activity monitor"[Title/Abstract] OR "digital health"[Title/Abstract] OR "digital public health"[Title/Abstract] OR "digital intervention*"[Title/Abstract] OR uhealth[Title/Abstract] OR uhealth[Title/Abstract] OR m-health[Title/Abstract] OR e-health[Title/Abstract] OR ehealth[Title/Abstract] OR mhealth[Title/Abstract] OR "Mobile health"[Title/Abstract] OR telemedicine OR telehealth[Title/Abstract] OR Telecare[Title/Abstract]) AND ("cost-effectiveness"[title] OR "cost-benefit"[title] OR "cost-utility"[title] OR "cost-minimization"[title] OR "cost-minimisation"[title] OR "cost-consequences"[title] OR "cost-consequence"[title] OR "economic evaluation"[title])

Textbox 1: Search strategy M3

The research question focused on decision modeling as this was expected to be of particular relevance for the economic evaluation of DiPHs. Finally, studies were selected if they used digital interventions, were within the field of primary prevention or health promotion, and conducted economic evaluations using decision analytical modeling. In addition, all studies that dealt with digital health and discussed their methodologies were selected from this search. These studies formed the basis of M2. Further trial-based economic evaluations were collected as examples for M1. After the initial search on 4th December 2020 and the COVID-19 pandemic was potentially a driver for new digital applications, the search was updated during the publication process on June 1st, 2022.

A critical assessment of methodological transparency was conducted using the established CHEERS (Husereau et al. 2013). Information on the interventions and methods used as well as the incremental costs were extracted. A detailed analysis of the incremental cost-effectiveness ratios (ICERs) was not possible due to the diversity of the interventions. Therefore, the quantitative results are presented in a tabular format only.

A.2.4. Methods of module 4 – Carbon footprint of virtual care

M4 aimed to assess the current evidence on the CF of virtual care interventions and its transparency. Given that there were no standardized reporting guidelines for carbon footprint calculations in the healthcare sector, one was developed within the scope of this study.

This study can be classified as a systematic review, as it involved a comprehensive double-independent search, as well as a critical appraisal of applied methods and a discussion of the uncertainty of findings.

(("carbon footprint"[MeSH Terms] OR ("carbon"[All Fields] AND "footprint"[All Fields]) OR "carbon footprint"[All Fields]) OR footprint[All Fields] OR (ecological[All Fields] AND footprint[All Fields]) OR ("greenhouse gases"[MeSH Terms] OR ("greenhouse"[All Fields] AND "gases"[All Fields]) OR "greenhouse gases"[All Fields] OR ("greenhouse"[All Fields] AND "gas"[All Fields]) OR "greenhouse gas"[All Fields]) OR "life cycle assessment"[All Fields] OR co2eq[All Fields] OR co2e[All Fields] OR (("carbon dioxide"[MeSH Terms] OR ("carbon"[All Fields] AND "dioxide"[All Fields]) OR "carbon dioxide"[All Fields]) AND equivalent[All Fields]) OR (co2[All Fields] AND equivalent[All Fields]) OR co2-eq[All Fields] OR (("carbon"[MeSH Terms] OR "carbon"[All Fields]) AND emission[All Fields]) OR (("carbon"[MeSH Terms] OR "carbon"[All Fields]) AND reduction[All Fields])) AND (("telemedicine"[MeSH Terms] OR "telemedicine"[All Fields]) OR ("remote consultation"[MeSH Terms] OR ("remote"[All Fields] AND "consultation"[All Fields]) OR "remote consultation"[All Fields] OR "teleconsultation"[All Fields]) OR telecare[All Fields] OR telediagnosis[All Fields] OR ("telemedicine"[MeSH Terms] OR "telemedicine"[All Fields] OR "telehealth"[All Fields]) OR telemonitoring[All Fields] OR tele-medicine[All Fields] OR tele-consultation[All Fields] OR tele-care[All Fields] OR tele-diagnosis[All Fields] OR tele-health[All Fields] OR tele-monitoring[All Fields] OR (virtual[All Fields] AND care[All Fields]) OR "virtual clinic"[All Fields] OR (smart[All Fields] AND care[All Fields]) OR (("health"[MeSH Terms] OR "health"[All Fields]) AND app[All Fields]) OR (intelligent[All Fields] AND ("health"[MeSH Terms] OR "health"[All Fields])) OR "electronic health"[All Fields] OR ("Digit Health"[Journal] OR ("digital"[All Fields] AND "health"[All Fields]) OR "digital health"[All Fields]) OR ("videoconferencing"[MeSH Terms] OR "videoconferencing"[All Fields]) OR ("videoconferencing"[MeSH Terms] OR "videoconferencing"[All Fields] OR "videoconference"[All Fields]) OR ("remote consultation"[MeSH Terms] OR ("remote"[All Fields] AND "consultation"[All Fields]) OR "remote consultation"[All Fields]))

Textbox 2: Search strategy of M4 (PubMed)

A comprehensive search (see search term in Textbox 2) of PubMed, Web of Science, Scopus, CINAHL, and EconBiz was conducted in November 2019. Studies that provided information on the approach to GHG-emission-calculation, VC services, or primary studies in English or

German were included. To assess methodological transparency, a checklist based on the consolidation of three existing carbon footprint standards was developed. For the synthesis of the results, the developed checklist was also used for the extraction of the respective items if they were reported. The results of the studies were compared based on the saved carbon emission per patient or teleconsultation.

A.3. Synthesis of results

The following sections present the research results synthesized per research question because some research questions are addressed by more than one module.

A.3.2. Results of RQ1 – "What should be considered?"

To answer the question "What should be considered in the economic evaluation of DiPH interventions?" M1 gives a broader insight and provides basic methods for (economic) evaluation and M2 provides specific recommendations on economic evaluation with a focus on CEA and CUA.

Starting with the general question, what should be considered, there a various topics, which could be included in the evaluation of DiPH inerventions. Although this is not a part of the dissertation, a framework with co-authorship of the doctoral candidate (Pan et al. 2022) will be introduced to give an example for further aspects, which should be considered by evaluating DiPH interventions.

The framework distinguishes between different dimensions alongside which DiPH can be evaluated. The purpose is to assist in the development, evaluation, policy making or research and it was developed within the work of the Leibniz ScienceCampus Digital Public Health (Pan et al. 2022). The framework mainly asks what can be evaluated, rather than how it should be evaluated. It is divided into the following different areas:

- Health Conditions and Current Public Health Interventions Functionality of the Health Technologies
- Software Properties
- Human-Computer Interaction
- Infrastructure and Organization
- Implementation
- Health-related Effects

- Social, Cultural and Gender Aspects
- Cost and Economics
- Legal and Regulatory
- Ethics
- Data Security and Data Protection
- Sustainability

The domain Cost and Economics can be seen as a starting point in answering the RQ. Asking what should be considered prior the economic assessment, the framework asks for relevant costs, effects, payers and the payers' decision criteria. The framework also shows the possible usefulness of applying the methods for decision makers. It is divided in cost of a targeted disease, cost-effectiveness related to various endpoints and the cost of implementing DiPH intervention over time (budget impact analysis).

Main findings M1

The chapter is divided into two parts: First, it is discussed what the evidence is and what methods are available to evaluate effectiveness. Second, it is discussed what the evidence is and are appropriate methods to evaluate the cost-effectiveness of DiPH. The latter draws upon the preliminary considerations on relevant costs, payers and decision criteria as well as the point of the cost-effectiveness of various endpoints from the framework (Pan et al. 2022) and further elaborates on these considerations.

The main findings from M1 are that the economic evaluation of DiPH should consider the extent to which the decision problem concerns the choice of perspective and associated endpoints. Four context of decision problems are stated and methodological considerations are proposed to evaluate cost-effectiveness.

First, frequently, a private decision by individuals can be assumed. There, users have to decide whether or not to use the DiPH intervention. This can be relevant when choosing an app to improve physical activity, as there is an ever-increasing number of apps freely available or offered to consumers on private markets and an individual selection process needs to be made. A second situation could be a coverage decision in the health sector if a DiPH intervention is funded by the national health system or health insurance. In this case, CEA and CUA can be an appropriate method, because they incorporate the respective perspective. This will be the focus of the main results of M2. A third case would be a situation in which more consequences than just those of the health system are to be included, for example, if an intervention promotes the behaviour of using bicycles instead of cars, so that not only health but also other policy aims like environmental ones are pursued. A fourth decision problem could arise for a company that wants to use a DiPH for workplace health promotion. In this case, the decision maker (manager) might be interested in the return on investment. M1 illustrates the importance of different evaluation perspectives for DiPH interventions (such as physical activity apps), which differ from public health topics like newborn or colon cancer screening conducted in a healthcare setting where a healthcare payer perspective is relevant.

Main findings M2

Since formal health economic evaluation is most likely to be conducted by health care payers, it is worth taking a look at methods that appear useful for coverage decisions. In the following, the focus will be on CEA and CUA, even if some statements also apply to other methods. Structured on CHEERS items, M3 gives guidance on how established economic evaluation methods should be used.

Summarizing very briefly, the title and abstract should clearly state what the digital component of the intervention is, so that evidence compilation within systematic reviews can also search for the respective technologies. Study protocols (called health economic analysis plan) for trial and model-based economic evaluations can also help to discuss the question addressed in M1 - before conducting an experiment or collecting evidence from a model. Regarding study population, M3 discusses that effectiveness across different groups is likely to differ. For example, while a smartphone app based weight loss intervention may be very effective for individuals with obesity, it is less effective in a general population – which is relevant because evidence may only be available for this single target populations.

Regarding comparators, firstly, the intervention should be described in detail, reflecting particularities in terms of digital properties. This is because there are many smartphone apps and, in the example of a weight loss app, there will be differences in what content is delivered, how it is delivered and whether there are interfaces to other systems. Secondly, there are particularities with regard to the selection of comparators, which means that, ideally, all non-digital interventions should also be used as comparators for digital interventions. However, of course, this may not always be feasible. A detailed uncertainty analysis can help here.

With regard to the choice of perspective, this study suggests to broaden the perspective, as DiPH is more likely to be intersectoral than other interventions, and to generate more than just health outcomes. Here, in addition, a perspective is proposed that also accounts for environmental scarcities that includes the calculation of carbon emissions. Preventive interventions have current costs and future benefits (Haddix et al. 2002). This also concerns preventive DiPH interventions, which, for example, reduces the risk of developing diabetes over a long period of time. However, digital intervention may have special costs for updates to remain in function.

As far as the measurement and evaluation of outcomes is concerned, rapid technological development may make it necessary to use alternative study designs instead of time-consuming RCTs. Economic evaluation using decision-analytic modelling would offer the possibility to synthesise such different forms of evidence.

The question of costs can be important in the economic evaluation of DiPH, as there are specific costs related to both the content of the intervention and the technological delivery. On the other hand, costs arise during the development of an intervention as well as during and after it (see Figure 1 for an overview). In addition, costs may be incurred for special aspects of digital health services, such as data security (see also: Agarwal et al. 2016)).

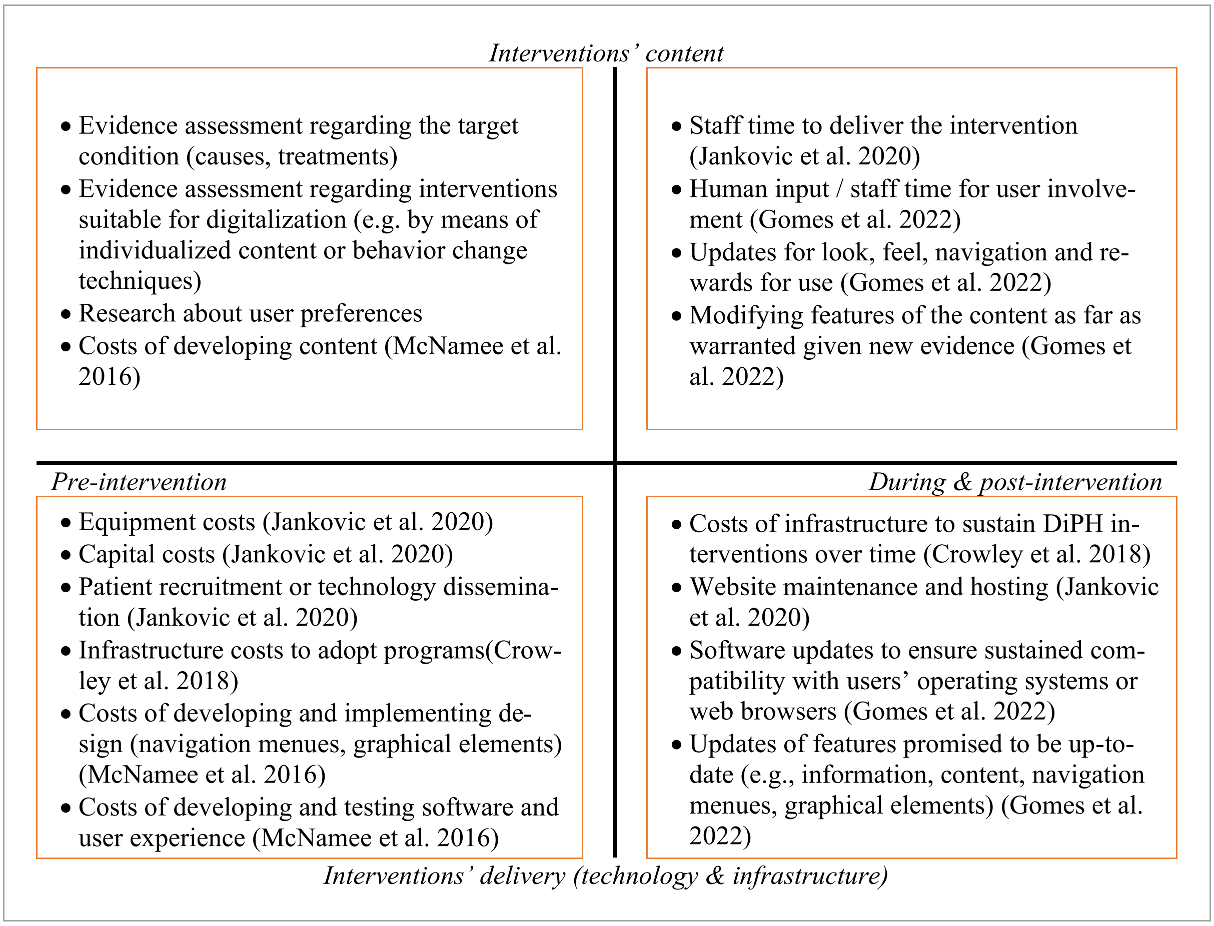

Figure 1: Potentially relevant costs specific for DiPH interventions (taken from M2)

Having already suggested in this thesis' introduction that model-based economic evaluation is of particular relevance for DiPH, M3 also notes that there are further reasons for using model-based economic evaluation for (preventive) DiPH. First, the possibility to model long-term effects; second, the possibility to synthesize different sources of data; and third, the consideration of technological dynamics through scenario analysis and the uncertainty of the results.

Zeeb et al. (2020) stated that topics of DiPH also include health inequalities in addition to a population perspective and a focus on prevention and health promotion. This is in line with CHEERS 2020 item "distributional effects". M3 notes that digital infrastructure can be unevenly distributed across populations which should be taken into account in economic evaluation.

A.3.1. Results of RQ2 – "What is the health economic evidence?"

RQ2 explores the health economic evidence of preventive DiPHs for economic evaluations that use decision-analytic modeling. To answer the research question, M3 identifies existing model-based economic evaluations and assesses how these studies were designed.

The systematized review, M3, included fourteen economic evaluations using decision analytic modeling (for references see M3). Regarding the question of existing economic evaluations of DiPH, interventions mainly targeting physical activity, weight loss, and smoking cessation were identified. Further targets were general behavioral changes in a group of students or menstrual health management. The intervention types included web-based applications, smartphone app-based interventions, text messaging-based interventions, or e-learning devices. Moreover, besides the evaluation of stand-alone interventions, interventions exist that promote a variety of existing smartphone apps; for example, Cleghorn et al. modeled an on–off campaign to promote existing weight loss apps (under NZ$ 4 per download). Figure 2 summarizes the intervention's characteristics.

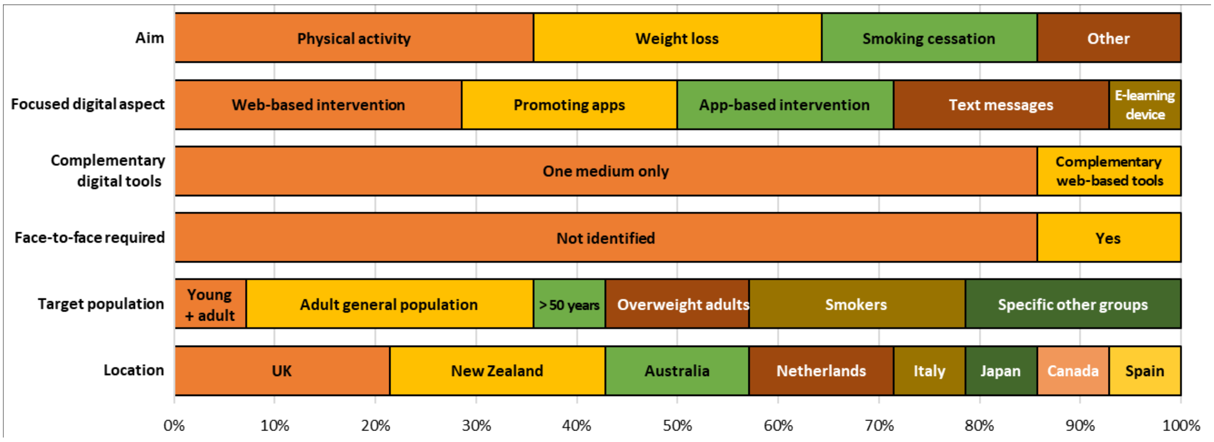

Figure 2: Intervention's characteristics (taken from M3)

The economic evaluations were mainly CUA; three studies conducted an additional CEA. Half of the included studies used Markov models, while four used multistate life table models, two used discrete event simulations, and one used a microsimulation model. Ten studies chose lifetime horizons. Figure 3 depict the evaluation methods details.

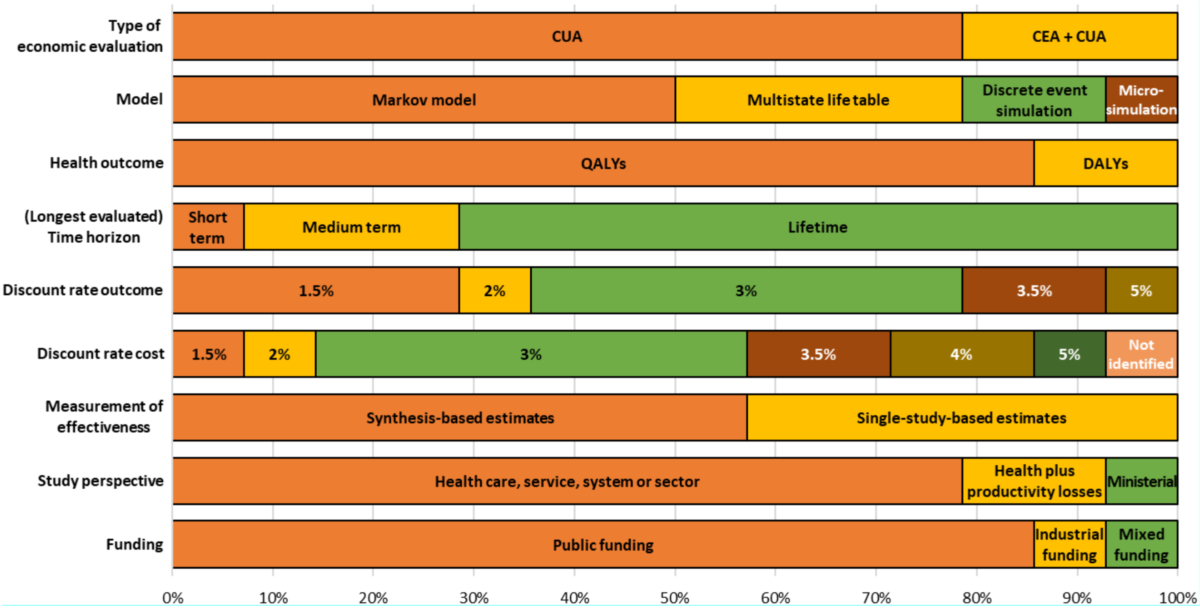

Figure 3: Evaluation methods (taken from M3)

Among all studies that used QALYs as a generic health measure, a mean value of € 21.430 per QALY can be calculated. However, the interventions are very different, which is why this mean value is only meaningful to a limited extent. The individual incremental cost-effectiveness ratios, which describe the cost per health outcome (in this case cost per QALY), can be found in Table X.

Authors	Intervention	Delivery	ICER	Currency per Health-outcome	Country	Price-year	ICER € per QALY	Note
Guerriero et al.	Smoking cessation	Text messages	-1,431	GBP per QALY	United Kingdom	2009-2010 (2010 used)	-1,616.89	Only weighed average *ICER = -41,509/29
Jones et al.	Weight loss	Promoting apps	-0.00029	NZ$ per QALY	New Zealand	2011	-0.00016	Price-year referred to Cleghorn et al.; * ICER=181/-606000
Cheung et al.	Smoking cessation	Web-based	0.00114	Euro per QALY	Netherlands	2016	0.00105	Price-year not identified. Literature search has ended in 2016. Only lifetime horizon considered; *ICER=20,953.83/18,301,195.32
Cobos-Campos et al.	Smoking cessation	Text messages	1327	Euro per QALY	Spain	2018	1,496.81	Only Woman & Health system perspective considered
Burn et al.	Physical activity	Text messages	8,608	AUS$ per QALY	Australia	2014	4,458.14	
Rondina et al.	Physical activity	App-based	11,113	CAD per QALY	Canada	2018	6,525.23	
Peels et al.	Physical activity	Web-based	10,100	Euro per QALY	Netherlands	2011	9,423.44	Only lifetime scenario
Song et al.	Menstrual management	App-based	1,914,285	Yen per QALY	Japan	2017	13,132.01	*ICER = 134,000/0.07
Kruger et al.	Behaviour change (mixed)	Web-based	22,844	GBP per QALY	United Kingdom	2012	25,186.97	Only the "Implementation at University of Sheffield"-scenario
Cleghorn et al.	Weight loss	Promoting apps	79,700	NZ$ per QALY	New Zealand	2011	41,834.45	
Mizdrak et al.	Physical activity	Promoting apps	81,000	NZ$ per QALY	New Zealand	2011	42,516.82	
Miners et al.	Weight loss	E-learning device	102,000	GBP per QALY	United Kingdom	2009	114,211.27	Only Scenario A

Table 1: Results of the economic evaluations (Taken from M3)

In addition to the evidence on economic evaluations using decision analytical modelling, parts of these dissertations also contain examples of evidence from trial-based economic evaluations in M1. However, these are not relevant to answering the research question.

A.3.3. Results of RQ3 – "What is the evidence on the carbon footprint?"

Answering the research question "What is the evidence on CO2 emissions resulting from digitalization in the public health sector?" is based on M4. One outcome of M4 is a reporting guideline for carbon footprint calculations. The checklist was consolidated from three existing standards and resulted in 22 items. This checklist was used to extract information from the studies and assess their methodological transparency. The original search and update yielded a total of 23 included studies. Most of the studies were in primary, secondary or tertiary care with different virtual care, virtual clinic or telemedicine interventions.

Regarding the context of DiPH of this doctoral thesis, two studies are of particular interest. One study is the environmental footprint of electronic health records (Turley et al. 2011). Another study is briefly presented below as it falls within preventive DiPH. Smith et al. (2013) estimated the carbon footprint of a smoking cessation intervention delivered by text message support, telephone counselling and individual counselling. Travel, building, energy and technological emissions were taken into account in their calculation. As a result, a group of 1,000 participants emitted 8,143 kg CO2e for text-message support, 8,619 kg CO2e for telephone counselling and 16,114 kg CO2 for group counselling.

The examination of the studies included a quality check based on the developed checklist. Figure 4 shows that some items were rarely reported. These include, for example, the definition of system boundaries and the conduct of sensitivity analyses. On average, 31% of the items were reported. No consistent average value could be calculated for all studies because different results were obtained (CO2e or CO2 per patient or consultation).

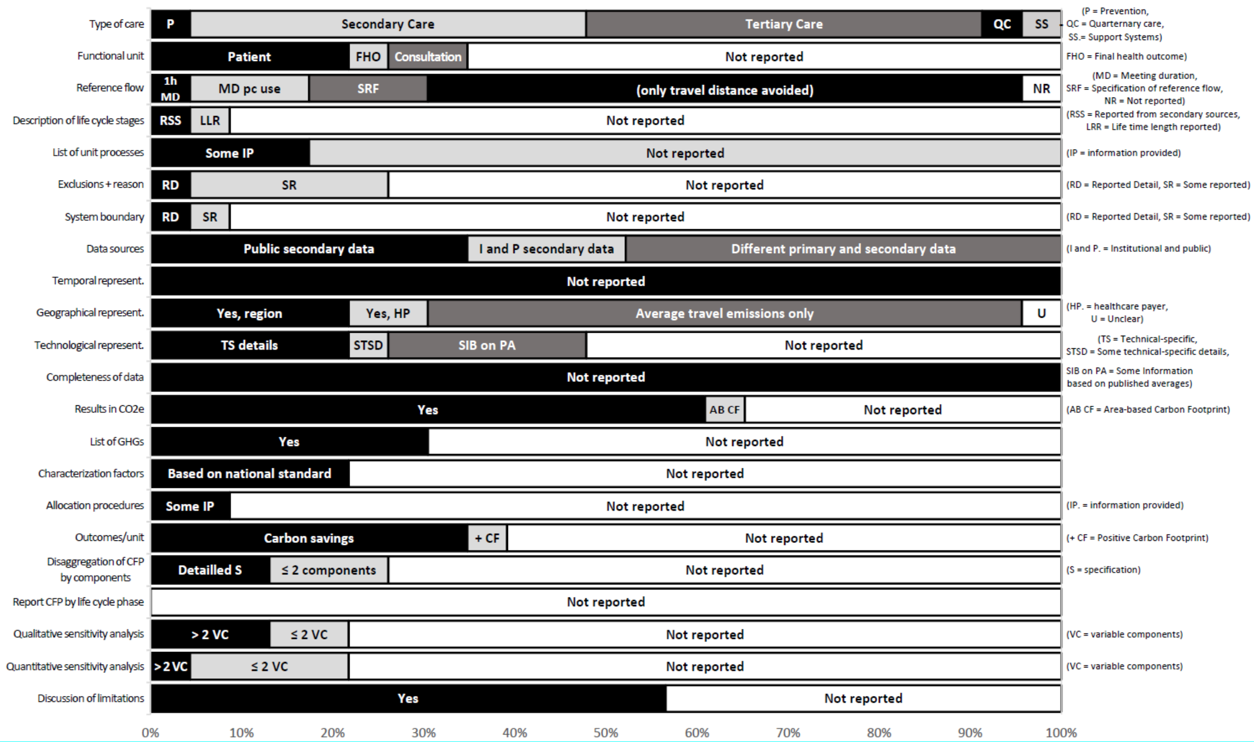

Figure 4: Summary of the results of the carbon footprint analyses (taken from M4)

A.4. Discussion

A.4.1. Interpretation

DiPH is a new field where model-based economic evaluation offers advantages for modelling long-term effects, especially in preventive DiPH interventions. However, investigated interventions based on relatively old technologies (e.g., web-based) for which it is unclear whether the effectiveness is lower than for more recent interventions. Further potential specifics of economic evaluation have not been widely implemented in the identified evaluations. One example is that only two of the 14 identified economic evaluations have a broader perspective than just a healthcare payer perspective.

A.4.2. Limitations

There are several limitations of this doctoral thesis.

M1 and M2 were based on all study types and had no systematic critical appraisal of the evidence. Nevertheless, the methods were chosen to provide an overview of current considerations in the health economic evaluation of digital public health. DiPH is rapidly changing due to technological innovations, so empirical evidence, including the newest technologies, is scarce. Therefore, all types of studies were used to gain a comprehensive overview. However, this has the advantage that these identified potential specifics of DiPH can influence a study design of a best-practice economic evaluation.

M3 was a systematic review and thus lacked the double-independent extraction of content and quality review that would have been mandatory in a systematic review. However, the title and abstract were screened in a double-independent process. The choice of single extraction was also because the author of this paper was intended for sole authorship because it is required to be the sole author of at least one module. M3 was also limited to primary prevention, so it is possible that there are other model-based economic evaluations in other areas of prevention. However, the focus of the study was to identify interventions that are not typically eHealth interventions aimed at treating individual diseases. It was limited to primary prevention in order to have a homogeneous study group and because other forms of prevention also include treatment, or at least there can be difficulties in distinguishing between them. Furthermore, only model-based economic evaluations were included, and other types of studies (e.g. trial-based) were omitted. However, this focus was also justified by the future research project to conduct a model-based economic evaluation.

M4 was restricted to carbon footprint, although other environmental effects could be investigated by using LCA methodology. However, against the background of climate change, this seemed relevant. Furthermore, mainly telemedicine applications are included in the review. This is due to an exploratory search, where the field of telemedicine was much studied, but in our understanding of DiPH (which is not only the treatment of individuals), there was a lack of evidence. At least one exemplary calculation of environmental effects for DiPH was identified. In view of the growing evidence in the meantime, a focus on preventive DiPH might be appropriate for future research.

However, as the most important limitation of this dissertation, it could be considered that there is no empirical module. The empirical module that might fit this thesis is a best-practice cost-utility analysis based on the findings of M1 and M2. Unfortunately, this empirical study was delayed up to a time right after finishing this thesis for several reasons. First, the original research plans had to be modified to include the book chapters in M1 and M2 and the systematic review in M4. Second, to ensure that the selected case study appropriately represents the challenges identified within the campus, results from other sub-projects had to be awaited. Third, now, based on M1 and M2 we have more knowledge about DiPH-specific evaluation needs and can explore this.

Nevertheless, as implications of this study, at least preliminary work on the cost-effectiveness analysis can be presented. The work was also prepared and submitted as an abstract for the annual conference of the German health economics association (Deutsche Gesellschaft für Gesundheitsökonomie e.V.). The submitted abstract can be found in Appendix 2. Further details are reported in the implications section.

A.4.3. Implications

The results of the individual modules have direct implications for further research, both at the methodological and the applied level, as well as for decision-making on DiPH.

M1 implies that there is a need to explore other methods for evaluating effectiveness which may also change the way how cost-effectiveness of DiPH can best be assessed. Also, economic evaluations of DiPH need to account to a larger extent for different perspectives than evaluations of other interventions.

M2 results in implications for direct methodological recommendations, especially in evaluating the cost-effectiveness of preventive DiPH interventions, particularly with regard to the potential use of model-based economic evaluation. The synthesis of health and other outcomes in model-based economic evaluation through the use of broader perspectives also implies the requirement for the generation of new evidence, e.g. productivity savings from the use of DiPH interventions, or evidence on external costs associated with DiPH interventions.

Implications of M3 include that the existing evidence not necessarily meets the requirements set by DiPH. Also model-based analyses are subject to various limitations. There is thus a need for further evidence generation in this field.

M4 provides a new benchmark of how to report the methodology of CF analyses in a more transparent way. This may be a first step towards including CF into the transparency catalogues of the EQUATOR network like the PRISMA statement or the CHEERS. Higher methodological rigor is needed, as the evidence found was mainly based on saved driving distance in telemedicine applications. Future carbon footprint calculations should address whole interventions and compare them with each other. Rather than just assessing saved emissions from avoided vehicle travel, all carbon emissions and savings ought to be included into the analyses. In the example of telemedicine, this includes, for example, additional emissions caused by manufacturing new IT systems.

Based on this, two concrete implications arise in the form of new research projects. Firstly, a study design for a best-practice economic evaluation of a DiPH intervention. And, secondly, the elaboration of how economic evaluation and carbon footprint calculations can be linked:

A.4.3.1 Economic Evaluation of DiPH case study

Based on the outcomes for RQ1 and RQ2, it has been shown that the relevant considerations for the economic evaluation of DiPHs are not always taken into account. This leads to the need for further research into the best practices for economic evaluations of a DiPH intervention. Following the consideration of RQ1, the following section outlines how models can be designed based on this dissertation. As mentioned in M2, the CHEERS statement requires a health economic analysis plan. To discuss the selection of evaluation method, time horizon and other components of an economic evaluation, this health economic analyses plan (study protocol) outlines a follow-up research project where an economic evaluation of digital weight loss interventions will be conducted. The following paragraph provides a summary of the research project based on an abstract submitted to the DGGÖ on November 20th, 2022 (see A.7. Appendix):

While the question is framed by the consideration of primary prevention, and the impact of new technologies such as wearables, the question is whether adding components improves or worsens the cost-effectiveness of an intervention. To model the long-term health consequences, we will use the population health model DYNAMO-HIA (Lhachimi et al. 2012), which was applied for various interventions, for example, tax on processed meat (Schönbach et al. 2019). We will model how the long-term prevalence of the chronic diseases heart disease, diabetes and stroke changes if an intervention lowers individuals' body mass index. Health endpoints are transferred to quality-adjusted life years according to the German value set for EQ-5D-5L to obtain a generic health measure (Ludwig et al. 2018). Evidence regarding the effectiveness of comparators with different digital components will be taken from the literature, such as the meta-analysis by Antoun et al. (2022). Accordingly, in the specific example of the identified meta-analysis (Antoun et al. 2022) the comparator is no intervention compared to (i) a smartphone app, (ii) app and tracking device; (iii) app and behavioural intervention; (iv) app and tracking device and (v) app, behavioural and social support.

Given that the evaluated intervention is digital, there are more DiPH specifics that are accounted for in the economic evaluation methods. First, we adopt a societal perspective and use a lifetime perspective, which is appropriate in the context of the preventive DiPH intervention. Second, a specific uncertainty analysis is planned that calculates, for example, how many participants are necessary for an intervention until the ICER of an intervention exceeds certain established thresholds since high fixed costs are distributed over many people. Third, in a follow-up project, we plan also to evaluate environmental effects. This should include, on the one hand, a cost-based assessment of environmental impacts of the intervention using EEIO-LCA-derived emission factors. On the other hand, a process-based LCA is planned to determine the environmental effects of the digital device used as the most important product within the intervention.

A.4.3.2 Integration of carbon footprint analysis in economic evaluation

Based on RQ1/M2, an implication for further research is the adoption of a broader perspective to address not only health outcomes but also other outcomes. An example given is a planetary perspective, which is justified as it can be assumed that in a time when global warming is to be limited, such outcomes are also relevant for decision-makers. Furthermore, it can be assumed that there are additional emissions that arise as a result of digital technologies, for example when new servers are manufactured, operated and disposed. One way to extend the cost perspective to a planetary one is to add a carbon footprint calculation. This method was introduced with M4, the evidence was compiled and a checklist for assessing the methodological transparency was provided.

Since both economic evaluation and carbon footprint methodology can be relevant for decision-making and assess an intervention, the question arises how carbon footprint can be considered in economic evaluation. Assuming that the economic evaluation is recognised as evidence by decision-makers, it can be considered to what extent calculation bases for carbon footprint calculations have already been collected in the economic evaluation.

As mentioned above, CHEERS are an established reporting standard and provide guidance for relevant components in economic evaluation. The checklist developed in M4 is an equivalent for carbon footprint calculations. For a future research project, one aim could be to combine these two reporting standards. For this, firstly, it should be identified which variables are shared by both methodological frameworks and only need to be recognised through different terminology; and secondly, it needs to be determined which information should be additionally reported / collected.

An example of the same basis for calculation is the reference flow as one important element in CF analyses, which is defined as a "measure of the inputs to or outputs from processes in a given product system required to fulfil the function expressed by the functional unit" (European Committee for Standardization 2018). This corresponds with the description of the intervention / comparator in the economic evaluation (e.g. "A person is provided with a fitness tracker with a corresponding app for three months within intervention X").

As M2 elaborated, there also seems to be overlap in the use of resources. Traditionally, cost analysis consists of three steps of cost identification, measurement in physical units and valuation. Here, it appears quite natural to include a planetary perspective in terms of carbon emissions. This can be assessed on the basis of cost-based emission factors (in the case of EEIO-LCA) or of emission estimates associated directly with the physical amount of resources (in the case of process-based LCA). Further work on such a framework is necessary which could be based on several consensus rounds of experts both of health economics and of LCA.

A.5. Conclusions

While economic evaluation can draw upon established standard methods, the decision-making context of DiPH interventions may require a broader perspective. One such perspective can be the evaluation of planetary sustainability in the light of the overall goal to reduce greenhouse gases.

This dissertation has demonstrated that there are (preventive) DiPH interventions whose incremental cost-effectiveness rate is below recognised thresholds, even though heterogeneity makes comparison difficult. In terms of planetary sustainability, there are digital interventions that have the potential to reduce GHG, although they are often methodologically limited.

Further research is needed to ensure that future developments in DiPH make use of this potential and lead to cost-effective or even cost-saving public health interventions which additionally provide benefits to the ecosystems on which the health of humanity depends.

A.6. References

Agarwal, S., et al. (2016). "Guidelines for reporting of health interventions using mobile phones: mobile health (mHealth) evidence reporting and assessment (mERA) checklist." Bmj **352**: i1174. DOI: 10.1136/bmj.i1174.

Antoun, J., et al. (2022). "The Effectiveness of Combining Nonmobile Interventions With the Use of Smartphone Apps With Various Features for Weight Loss: Systematic Review and Meta-analysis." JMIR Mhealth Uhealth **10**(4): e35479. DOI: 10.2196/35479.

Bathia, P. C., C.; Draucker, L.: Rich, D.; Lahd, H., Brown A. (2011). Greenhouse Gas Protocol. Product Life Cycle Accounting and Reporting Standard, World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). **2021**.

Bjørn, A., et al. (2018). Main Characteristics of LCA. Life Cycle Assessment: Theory and Practice. M. Z. Hauschild, R. K. Rosenbaum and S. I. Olsen. Cham, Springer International Publishing**:** 9-16. DOI: 10.1007/978-3-319-56475-3_2.

Briggs, A., et al. (2006). Decision modelling for health economic evaluation. Oxford, Oxford Univ. Press.

Crowley, D. M., et al. (2018). "Standards of Evidence for Conducting and Reporting Economic Evaluations in Prevention Science." Prevention Science **19**(3): 366-390. DOI: 10.1007/s11121-017-0858-1.

Department of Health and Social Care. (2018, 2018). "Prevention is better than cure: our vision to help you live well for longer " Retrieved 17 Aug 2021, from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/753688/Prevention_is_better_than_cure_5-11.pdf.

Drummond, M. F., et al. (2015). Methods for the Economic Evaluation of Health Care Programmes. Oxford, Oxford: Oxford University Press.

European Committee for Standardization (2018). "Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification (ISO 14067:2018); German and English version EN ISO 14067."

Gal, R., et al. (2018). "The Effect of Physical Activity Interventions Comprising Wearables and Smartphone Applications on Physical Activity: a Systematic Review and Meta-analysis." Sports Med Open **4**(1): 42. DOI: 10.1186/s40798-018-0157-9.

Ghani, Z., et al. (2020). "The Cost-Effectiveness of Mobile Health (mHealth) Interventions for Older Adults: Systematic Review." International Journal of Environmental Research and Public Health **17**(15): 12. DOI: 10.3390/ijerph17155290.

Gomes, M., et al. (2022). "Economic Evaluation of Digital Health Interventions: Methodological Issues and Recommendations for Practice." Pharmacoeconomics: 1-12. DOI: 10.1007/s40273-022-01130-0.

Grant, M. J. and A. Booth (2009). "A typology of reviews: an analysis of 14 review types and associated methodologies." Health Information & Libraries Journal **26**(2): 91-108. DOI: https://doi.org/10.1111/j.1471-1842.2009.00848.x.

Grant, M. J. and A. Booth (2009). "A typology of reviews: an analysis of 14 review types and associated methodologies." Health Info Libr J **26**(2): 91-108. DOI: 10.1111/j.1471-1842.2009.00848.x.

Haddix, A. C., et al. (2002). Prevention effectiveness: a guide to decision analysis and economic evaluation, Oxford University Press.

Hauschild, M. Z. (2018). Introduction to LCA Methodology. Life Cycle Assessment: Theory and Practice. M. Z. Hauschild, R. K. Rosenbaum and S. I. Olsen. Cham, Springer International Publishing: 59-66. DOI: 10.1007/978-3-319-56475-3_6.

Husereau, D., et al. (2022). "Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) statement: updated reporting guidance for health economic evaluations." BMJ **376**: e067975. DOI: 10.1136/bmj-2021-067975.

Husereau, D., et al. (2022). "Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) Statement: Updated Reporting Guidance for Health Economic Evaluations." Value Health **25**(1): 3-9.

Husereau, D., et al. (2022). "Consolidated Health Economic Evaluation Reporting Standards (CHEERS) 2022 Explanation and Elaboration: A Report of the ISPOR CHEERS II Good Practices Task Force." Value Health **25**(1): 10-31.

Husereau, D., et al. (2013). "Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement." Value in Health **16**(2): e1-5. DOI: 10.1016/j.jval.2013.02.010.

Jankovic, D., et al. (2020). "Systematic Review and Critique of Methods for Economic Evaluation of Digital Mental Health Interventions." Appl Health Econ Health Policy. DOI: 10.1007/s40258-020-00607-3.

Jiang, X., et al. (2019). "The Cost-Effectiveness of Digital Health Interventions on the Management of Cardiovascular Diseases: Systematic Review." Journal of Medical Internet Research **21**(6): N.PAG-N.PAG. DOI: 10.2196/13166.

Klasnja, P., et al. (2015). "Microrandomized trials: An experimental design for developing just-in-time adaptive interventions." Health Psychol **34s**(0): 1220-1228. DOI: 10.1037/hea0000305.

Laranjo, L., et al. (2021). "Do smartphone applications and activity trackers increase physical activity in adults? Systematic review, meta-analysis and metaregression." Br J Sports Med **55**(8): 422-432. DOI: 10.1136/bjsports-2020-102892.

Lhachimi, S. K., et al. (2012). "DYNAMO-HIA–a dynamic modeling tool for generic health impact assessments." PloS one **7**(5): e33317.

Ludwig, K., et al. (2018). "German Value Set for the EQ-5D-5L." Pharmacoeconomics **36**(6): 663-674. DOI: 10.1007/s40273-018-0615-8.

Masters, R., et al. (2017). "Return on investment of public health interventions: a systematic review." Journal of Epidemiology and Community Health **71**(8): 827. DOI: 10.1136/jech-2016-208141.

Mattila, T. J. (2018). Use of Input–Output Analysis in LCA. Life Cycle Assessment: Theory and Practice. M. Z. Hauschild, R. K. Rosenbaum and S. I. Olsen. Cham, Springer International Publishing: 349-372. DOI: 10.1007/978-3-319-56475-3_14.

McNamee, P., et al. (2016). "Designing and Undertaking a Health Economics Study of Digital Health Interventions." Am J Prev Med **51**(5): 852-860. DOI: 10.1016/j.amepre.2016.05.007.

Odone, A., et al. (2019). "Public health digitalization in Europe." Eur J Public Health **29**(Supplement_3): 28-35. DOI: 10.1093/eurpub/ckz161.

Page, M. J., et al. (2021). "The PRISMA 2020 statement: an updated guideline for reporting systematic reviews." BMJ **372**: n71. DOI: 10.1136/bmj.n71.

Pan, C. C., et al. (2022). "Developing and assessing Digital Public Health Interventions: A comprehensive framework. 1st version.", from https://www.lsc-digital-public-health.de/forschung/framework.html.

PAS 2050 (2011). "PAS 2050:2011. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.".

Ringeval, M., et al. (2020). "Fitbit-Based Interventions for Healthy Lifestyle Outcomes: Systematic Review and Meta-Analysis." J Med Internet Res **22**(10): e23954. DOI: 10.2196/23954.

Sanyal, C., et al. (2018). "Economic evaluations of eHealth technologies: A systematic review." PLoS One **13**(6): e0198112. DOI: 10.1371/journal.pone.0198112.

Schönbach, J.-K., et al. (2019). "What are the potential preventive population-health effects of a tax on processed meat? A quantitative health impact assessment for Germany." Preventive Medicine **118**: 325-331.

Silva, A. G., et al. (2020). "Effectiveness of Mobile Applications Running on Smartphones to Promote Physical Activity: A Systematic Review with Meta-Analysis." International Journal of Environmental Research and Public Health **17**(7): 2251.

Simera, I., et al. (2009). "The EQUATOR Network and reporting guidelines: Helping to achieve high standards in reporting health research studies." Maturitas **63**(1): 4-6. DOI: https://doi.org/10.1016/j.maturitas.2009.03.011.

Smith, A. J., et al. (2013). "The carbon footprint of behavioural support services for smoking cessation." Tob Control **22**(5): 302-307. DOI: 10.1136/tobaccocontrol-2012-050672.

Turley, M., et al. (2011). "Use of electronic health records can improve the health care industry's environmental footprint." Health Aff (Millwood) **30**(5): 938-946. DOI: 10.1377/hlthaff.2010.1215.

Unsworth, H., et al. (2021). "The NICE Evidence Standards Framework for digital health and care technologies - Developing and maintaining an innovative evidence framework with global impact." Digit Health **7**: 20552076211018617. DOI: 10.1177/20552076211018617.

Weatherly, H., et al. (2009). "Methods for assessing the cost-effectiveness of public health interventions: Key challenges and recommendations." Health Policy **93**(2): 85-92. DOI: https://doi.org/10.1016/j.healthpol.2009.07.012.

Weinstein, M. C., et al. (1996). "Recommendations of the Panel on Cost-effectiveness in Health and Medicine." Jama **276**(15): 1253-1258.

Wienert, J., et al. (2022). "What are Digital Public Health Interventions? First Steps Toward a Definition and an Intervention Classification Framework." J Med Internet Res **24**(6): e31921. DOI: 10.2196/31921.

Wong, B. L. H., et al. (2022). "The dawn of digital public health in Europe: Implications for public health policy and practice." Lancet Reg Health Eur **14**: 100316. DOI: 10.1016/j.lanepe.2022.100316.

World Health Organization. (2018, 2018). "Essential public health functions, health systems and health security: developing conceptual clarity and a WHO roadmap for action." Retrieved 15 Sept 2022, from https://apps.who.int/iris/handle/10665/272597.

Wright, M. T. (2021). "Partizipative Gesundheitsforschung: Ursprünge und heutiger Stand." Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz **64**(2): 140-145. DOI: 10.1007/s00103-020-03264-y.

Zeeb, H., et al. (2020). "[Digital public health-an overview]." Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz **63**(2): 137-144. DOI: 10.1007/s00103-019-03078-7.

A.7. Appendix of synopsis

A.7.1. Appendix 1: Abstract - Economic evaluation of case study

Abstract submitted to the annual conference 2023 of Deutsche Gesellschaft für Gesundheitsökonomie e.V.

The cost-effectiveness of digital public health weight loss interventions delivered by a smartphone app and wearable in Germany - a study protocol

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Background

Digital Public Health (DiPH) using new technologies such as smartphones or wearables to track physical activity provides novel options for prevention and has experienced increasing interest recently. DiPH might help to support the transmission from prevention to cure, for example by reducing obesity, thereby lowering the risk of developing heart disease, stroke and diabetes. It is unclear whether such an intervention has a higher incremental cost-effectiveness ratio (ICER) due to the addition of digital components (smartphone app or wearable) or a lower one, due to their positive impact on effectiveness.

Objective

Following the recent inclusion of health economic analysis plans into CHEERS, we present a study protocol for a model assessing costs and health impacts of different combinations of digital and conventional weight loss interventions in the setting of the German health system.

Methods

Cost-effectiveness is estimated from a societal perspective within the general population in Germany over a lifetime horizon. The base case is a control group of no intervention compared

to different combinations of smartphone app, tracking device and behavioural intervention. Cost (€) and outcomes will be discounted by 5 % using different discount rates including differential discounting in the sensitivity analysis. We apply the population health model DYNAMO-HIA to project the long-term prevalence of heart disease, stroke and diabetes and overall mortality for the general population. The effect estimates for each strategy will be based on the associated weight loss identified through a literature search. The incidence-prevalence-mortality profile will be based on publicly available health data. Health endpoints will be transferred to quality-adjusted life years, using the German value set for the EQ-5D-5L. Specific issues in the economic evaluation of DiPH interventions will be addressed in sensitivity analyses – for example, given high fixed costs and very low marginal costs of including additional users of weight loss apps, a scenario analysis of how many participants would be needed to render the app-alone strategy cost-effective at standard thresholds and cost saving. Also, given short technology life cycles and limited evidence about the long-term effectiveness, the impact of changing the duration of effectiveness on cost-effectiveness will be explored.

Expected results

The intervention potentially decreases the incidence of heart disease, stroke and diabetes. However, app-based DiPH might be cost-effective only for large numbers of users.

Expected discussion

The literature-based effect estimates might be based on (already) dated technologies and thus under-estimate effectiveness.

B. Main Part

B.1. Module 1

Title:

Evaluation [of Digital Public Health]

Authors:

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This is a modified version of the submitted manuscript. Modifications included formatting and changed the numbering of headings and textboxes.

B.1.1. Abstract

Evaluation of digital public health (DiPH) interventions is as necessary as the evaluation of any other medical or public health intervention. This chapter addresses the two most important dimensions of evaluation: effectiveness and cost-effectiveness. In doing so, we ask (i) what is already known about the (cost-)effectiveness of DiPH interventions and (ii) what should be considered if such interventions are undertaken.

Although the body of literature is growing rapidly, hard evidence is scarce, and the quality of existing evidence is poor. Effectiveness has only been proven in short-term observations when compared to no intervention and with outcomes measured using digital devices. For assessing Cost-effectiveness, it is important to distinguish between the different perspectives that may be relevant. Generally, studies give a wide range of results. Studies estimating return on investment from a company perspective estimate positive returns in studies with a low level of evidence, while randomized controlled trials (RCTs) show negative returns.

To guide further research, a framework was developed that might help in asking the right questions. Answering these questions needs a combination of well-established evaluation methods, which provide reliable evidence but might take too long, with alternative methods that generate evidence faster and might be used to screen where in-depth studies should be taken. In the future, the need to include planetary health in (economic) evaluation might be ever more acknowledged.

Keywords: cost-effectiveness, environmental impact, evaluation, effectiveness, digital public health

B.1.2. Introduction

The central concern of public health is to improve the benefits and efficiency of health-related interventions and to reduce health inequities while respecting the self-determination of individuals (1). Within the world of evidence-based medicine, this implies that interventions to improve health should only be conducted if the net benefit for users is proven. This requires a thorough evaluation of all new techniques and devices – also in the realm of Digital Public Health (DiPH). DiPH interventions, however, show features that might require an adaption of traditional evaluation frameworks. In this chapter, we, therefore, first explore what DiPH interventions are and which requirements for evaluation follow from that (section 3). We then discuss the effectiveness and efficiency of DiPH interventions (section 4). These discussions are centred around two questions: (i) what is the current evidence about the effectiveness, efficiency, and environmental impacts of DiPH interventions and (ii) what are eligible methods to evaluate effectiveness, efficiency, and environmental impact of DiPH interventions? We conclude with some take-home messages on what is vital for conducting appropriate evaluations of DiPH interventions (section 5).

Digital Public Health interventions

While medicine focuses on individual-level health, public health always relates to the health of a population. Public health "comprises the entirety of all social, political and organizational efforts aimed at improving the health situation, reducing the likelihood of illness and death and increasing the life expectancy of groups [of individuals] or entire populations. Public health includes all organized, multidisciplinary and multi-professional approaches in disease prevention, health promotion, disease control, disease management, rehabilitation and care [and therefore includes all three levels of prevention.]" (see: https://www.lsc-digital-public-health.de/forschung/glossary.html in orientation at Winslow, 1920). Following Zeeb et al. (2), DiPH can be seen as a comprehensive term for applying information and communication technologies related to public health (see also 3). While a consensus definition for DiPH is still lacking (4), it seems wise to regard the term in a rather encompassing way, including all electronic Health (eHealth), mobile Health (mHealth) and digital health tools and devices for the improvement of the health status of a population. Therefore, one should not only refer to primary prevention (i.e. intervening before a health problem occurs) but also to secondary (reducing the impact of disease by medical treatment) and tertiary prevention (i.e., rehabilitation) when talking about DiPH (4) (see chapter I.1 Why is it essential to address digital public health in an interdisciplinary way?).

In an age of rapid technological development, the number of hardware- and software-based digital technologies is increasing rapidly and has already led to many possible applications. For instance, the number of mHealth apps available in the Apple App Store was more than 50,000 in the second quarter of 2022 (5). Besides pure software products, devices such as fitness trackers, smartwatches and personal digital scales are also rising. These examples are just one sub-area of DiPH, which also extends to other health promotion and prevention types. Beyond health apps, possible DiPH interventions also include digital software used by health workers to notify health departments about new cases of a disease (6), Covid-19 contact tracking, digital applications of health insurances promoting healthy behaviour or partially compensating self-paid health services, or interventions that use any kind of digitally linked device (for example, a physical activity promotion intervention with wearable or digitally linked accelerometers, see: 7). Accordingly, we conclude that a wide variety of DiPH applications exists, and different requirements for the evaluation could play a role (8).

Not all new devices contribute to population health, so the need for evaluation is self-evident. However, the sheer speed of technological development generates questions for evaluation methods. Thorough evaluations might need more time than the life cycle of specific products takes. Consequently, the results of an assessment would be available only when the product is no longer in the market. Hence the question of how evaluations should be conducted arises. This question is even more relevant since, for example, digital health applications (DiGA) can be reimbursed by prescription in Germany.

B.1.3. Evaluation of Digital Public Health Interventions

Different aspects of an intervention can be evaluated. For digital tools, acceptance is a prerequisite for successful implementation. Since the 1980s, extensive research has produced several Technology Acceptance Models (TAMs) (9-12), which were later extended to the Unified Theory of Acceptance and Use of Technology (UTAUT model; 13). As there is already a broad body of literature on that and as the determinants of digital technology and other kinds of technology overlap in huge parts, we will not cover this here.

Instead, we will concentrate on effectiveness (with usability as a prerequisite) and efficiency as the most important aspects of evaluation in a world characterized by limited resources. Additionally, we will discuss the environmental impact, such as carbon emissions of DiPH interventions, since we believe this aspect will play a more significant role in the future.

It should be noted that other aspects, such as ethics, need to be considered when evaluating DiPH interventions. These aspects are covered in chapter II.2 Framework DiPH, which describes a newly developed comprehensive framework for developing and assessing DiPH interventions.

B.1.3.1. Effectiveness

From a public health point of view, it is crucial to disentangle potential financial gains for developers. These are essential for the implementation of innovations from possible health benefits for technology recipients in terms of user outcomes. This implies the assessment of benefit rather than mere technical effectiveness (14). The use of some technologies (e.g., health apps and wearables) could contribute to gains in at least two domains: (1) for individuals in prevention, health promotion, monitoring, management, and health education and (2) for healthcare policy-makers by providing real-life, objective, self-tracked, and longitudinal data (15), to decide which devices should be promoted and which shouldn't.

B.1.3.2. Exponential growth in literature on digital prevention and health promotion – but not much sound knowledge about effectiveness

The need to evaluate DiPH interventions has been extensively addressed in reviews with systematic methodologies, such as systematic, scoping, or rapid reviews and overviews of reviews (14). Since the introduction of affordable internet on personal computers around 2000 and the smartphone technology around 2010, the scientific literature on digital behaviour change techniques primarily targets physical activity and a healthy diet (16). Digital interventions targeting healthy lifestyles may benefit various population groups, such as older adults (17). So far, however, the quality of existing evidence and reporting of DiPH in systematic reviews is poor (14, 18).

It appears that DiPH interventions supported by digital technologies contribute to small health benefits under the following conditions: (1) in the short-term (i.e., pre- vs post-intervention), (2) relative to no intervention, (3) for outcomes that can be measured objectively using digital devices (e.g., smartphones or activity trackers), such as steps or own weight per day, and (4) if human support is provided (i.e., technical support or social network established with other study participants or study staff) (17, 19). Although small health benefits may not be clinically meaningful, they could be sufficient to empower some populations, such as older people, to perform daily tasks required for independent living (19). However, DiPH interventions are not superior to non-digital interventions. This is especially the case in real-world conditions (i.e. when they are used without human support). The long-term maintenance of their health benefits is unknown, and their effectiveness for difficult-to-measure outcomes, such as well-being, is unclear (17, 19). Evaluation of DiPH technologies is not easy to accomplish for the following reasons.

First, it is unclear what methods should be used to evaluate the user outcomes of DiPH interventions. According to past reviews, the development of DiPH interventions is often guided by evaluation frameworks focusing on various aspects of behavior change theory (14). However, these reviews rarely addressed the theoretical underpinning of outcome evaluation, indicating that this topic was either not mentioned in the primary studies or not coded by review authors (14). Thus, complex or new methods may be required to adapt existing evaluation frameworks to evaluate user outcomes of digital health interventions (20).

Second, evaluation of effectiveness of any health intervention requires a standardized terminology that clearly defines the components and mode of delivery as well as the desired outcomes. Both requirements are not fulfilled as yet in the new field of DiPH interventions. For example, there was surprisingly little overlap in the primary studies included in the past reviews. Nevertheless, all reviews focused on common intervention types (all digital) and health targets (all on physical activity outcomes) (14). Such general lack of a common language was also evident in incomplete reporting of intervention details and outcomes in this new field (14). Thus, we require a standardization of terminology before we are able to evaluate the health outcomes of DiPH.

Third, the effectiveness of DiPH interventions is affected by a complex set of factors. Similar to any health intervention, the evaluation of the effectiveness of DiPH interventions should consider factors such as the dose-response relationship (i.e., higher and longer benefits with higher doses), the durability of any short-term effects in the absence of interventions, and the quality of adaptation towards the needs of the target population (e.g., children or older adults). One needs to consider two essential factors when evaluating DiPH interventions: First, the engagement with interventions (21), especially if such interventions do not involve any human support, and second any add-on health benefits relative to other traditional (non-digital) interventions (17). The following section will investigate the considering factors for the evaluation context. Herebey, we'll explain the adoption of evaluation frameworks, classic study designs usually used for evaluation purposes, alternative study designs for the digital environment, and digital data collection.

B.1.3.3. What factors to consider in the context of evaluation?

Evaluation frameworks

Frameworks that can be used for systematically evaluating digital interventions for public health purposes are still scarce. Most existing frameworks focus on evaluating digital technologies without considering public health-relevant aspects (22). To remedy this situation, members of the Leibniz ScienceCampus DiPH developed the first draft of a DiPH framework (see Chapter II.2 in this handbook and: 23). This process was based on three steps: (1) scoping review of existing public health and digital health frameworks, (2) mapping of identified public health and digital health frameworks on the structure of the Health Technology Assessment (HTA) Core model, and (3) consensus meeting with interdisciplinary experts from the Leibniz ScienceCampus DiPH. The DiPH framework consists of 210 questions structured in 13 domains (i.e., health conditions and current public health interventions, functionality of the health technologies, software properties, Human-Computer Interaction, infrastructure and organization, implementation, health-related effects, social, cultural and gender aspects, cost and economics, legal and regulatory, ethics, data security and data protection, sustainability) (23). As a next step, the Leibniz ScienceCampus DiPH will apply the framework in case studies (see chapter II.2 Framework DiPH).

Study designs

To assess the effectiveness of public health interventions, randomized controlled trials (RCTs) serve as a gold standard. However, due to the extended timeframe and rigidity of RCTs, these are perceived as not always optimal for evaluating DiPH interventions. DiPH interventions underlie the rapid development of digital technologies and are complex concerning user needs and intervention components. Alternative study designs, which consider the characteristics of DiPH interventions to a certain extent, are the continuous evaluation of evolving behavioral intervention technologies (CEEBIT), multiphase optimization strategy (MOST), sequential multiple assignment randomized trials (SMART), micro-randomized trials and N-of-1 trials (see Textbox 3).

Reviews reporting on the use of evaluation methods for digital health interventions found that RCTs are still more often used than alternative designs (24). For instance, a scoping review on evaluation methods applied to digital health interventions beyond RCTs included only eight studies on four alternative evaluation designs (i.e., factorial designs, stepped-wedge designs, SMART, micro-randomized controlled trials) (20). One reason for the infrequent use of alternative study designs is that they are considered to be more appropriate for intervention development (e.g., MOST, SMART, micro-randomized trial) rather than determining effectiveness (25) – and of course they are not the gold standard. Therefore some authors suggest conducting an RCT afterward (e.g. 26). At the moment, a clear recommendation regarding the best method for evaluating DiPH interventions cannot be given. Further research and discussion is needed (20).

Continuous evaluation of evolving behavioral intervention technologies (CEEBIT) (27)

Continuous evaluation concept which compares different interventions included in one digital tool. New interventions can be added at any time. Interventions with inferior effects are terminated.

Multiphase optimization strategy (MOST) (26)

Multiphase concept for selecting and refining intervention components, followed by testing the overall intervention using an RCT.

Sequential multiple assignment randomized trials (SMART) (26)
Test concept for comparing multiple time-adaptive treatment strategies. Randomization to conditions at different time points, depending on the outcomes of the intervention so far. Data from multiple experimental groups are combined to test research questions of interest.

Micro-randomized trials (28)(Klasnja et al. 2015)

Evaluation design for Just-in-Time Adaptive Interventions (JITAIs). Participants are randomized to different intervention conditions at critical time points. Short-time effects of different conditions are estimated and tested.

N-of-1 trials (29)

Trials with only one participant, who receives different interventions repeatedly in a randomized order. Individual intervention effects for the participant are estimated. Results of multiple N-of-1 trials can be combined.

Textbox 3

Example of an alternative study design: N-of-1 trials

One example of an alternative evaluation method is the N-of-1 trial (for an overview, see 29). In an N-of-1 trial, the effect of an intervention is evaluated for an individual participant. The participant receives the intervention or a control for a predefined study duration, usually in a randomized order. The outcome is repeatedly recorded and compared between intervention and control periods. The effect of the intervention can be estimated and tested. If randomization is used, the bias due to time-depending confounders is minimized (29). Comparing different N-of-1 trials gives information about the heterogeneity of effects in difference to RCTs where average effects are measured (30). The average impact on the population can be investigated when combining the results of multiple N-of-1 trials (29).

N-of-1 trials can be used to evaluate DiPH interventions that are applied on the individual level. The approach allows investigation of interindividual differences in intervention effects, for example, which elements of the intervention are effective for whom or whether there are different trajectories of change over time (30). Due to the cross-over type of evaluation, sample sizes are smaller than in RCTs. However, an N-of-1 trial cannot be applied in every situation. It requires a short-time intervention that can be randomized within a participant and an outcome that can be repeatedly and easily collected. An exemplary study was conducted by Sniehotta, Presseau (31), where the effect of goal-setting and self-monitoring of physical activity was tested in ten identical N-of-1 trials. Two participants each benefited significantly from goal-setting or self-monitoring. For the others, no significant effect could be shown.

Digital data collection

Digital and especially mobile technologies allow the collection of biological, behavioral, or environmental data (32). This is done by the technology/application itself or connected devices like pedometers or smartwatches. Using digital data creates unique opportunities and challenges for evaluating digital (public health) interventions.

Many digital technologies routinely collect data, due to technical reasons, as part of the functionality (e.g., apps used for monitoring) or for personalizing content. If these data are used for evaluation, we speak of secondary data analysis (see Chapter V.3 Use of secondary data for DiPH for a detailed discussion), as contrasted with data collected directly (primary) for a research question. Automatically collected data can be used to investigate user involvement (data traffic, number of downloads, use data). Also, effectiveness can be tested, for example, in physical activity. Possible outcomes for effectiveness include the number of steps, number of minutes in moderate-to-vigorous physical activity (MVPA), or total physical activity (TPA) in a chosen time period. The use of smartphones allows furthermore to include environmental covariates like the weather or GPS location in evaluation models.

If data are repeatedly collected, this allows modeling of changes over time and time-depending covariates. It may be of interest under which situations and for whom an intervention is effective. This is especially the case for interventions for behavioral change, as behavior is context-dependent. In psychology, such evaluation methods are called ecological momentary assessments (EMA) (33). The subjects' psychological state in EMA is repeatedly assessed at strategically selected moments in real-world environments.

One advantage of digitally collected data is a lower effort since participants do not have to come to the research centers for measurements. As data are collected in daily life, this approach leads to a high external validity. Additionally, digital data collection may lead to a high density of data. With appropriate statistical methodology, higher power and smaller sample sizes compared to traditional outcomes can be achieved (32). Study designs like micro-randomized trials or N-of-1 trials rely on a high number of data points over time.

However, one should be aware of the challenges if one chooses digital data collection. Technical problems may occur. If participants' own devices are used, the digital intervention has to work for different operating systems. Technical errors or connection issues may lead to missing data (34). Due to the real-life setting, the heterogeneity in the technology use of participants may reduce the internal validity. For example, the assessment of physical activity depends on carrying the smartphone or wearable on person at all times. Also, the technical literacy of a participant will influence the technology use. Taking these factors together, one has to expect missing values and high variability. To meet these challenges, a pilot study should be done to fix technical errors and to test whether the instructions are clear and understandable. Technical support may help people with problems due to low technological literacy. Lastly, an appropriate evaluation strategy should be used to account for time series structure and missing data.

B.1.4. Evaluation of cost-effectiveness

DiPH technologies consume limited resources, so effectiveness and cost-effectiveness are relevant for their evaluation. As defined by Drummond, Sculpher (35), economic evaluation compares two or more interventions in terms of their cost and consequences. However, which costs and which consequences are to be investigated depends on the decision context.

In the following section, we distinguish between four contexts of deciding about the acquisition of DiPH technologies from limited resources: private decisions of individuals acquiring digital technologies on markets, coverage decisions taken by decision-makers in the public health and healthcare system, public decisions of policy-makers with broader considerations than health alone and decisions by companies using DiPH interventions as investments into employee health. We briefly explain each context's essential characteristics, review the published evidence, and discuss methodological issues. Finally, we reflect on the possibilities of extending the economic evaluation perspective to a planetary perspective that does not only include the monetary costs.

Basic information on "What could be evaluated" in costs and economics has been presented as part of the DiPH framework [see II.2 DiPH Framework]. To get more detailed information on what are the methodological particularities in the economic evaluation of DiPH, we refer to chapter [IV3.3 EPHO8: Assuring sustainable organizational structures and financing]. Here, economic evaluation is introduced as a method to ensure sustainable financing of (digital) public health.

B.1.4.1. Informal private decisions about acquiring DiPH technologies

A central concept for economic evaluation linked to the decision context is the so-called "perspective", i.e., the question whose costs and benefits are considered. Unlike other public health interventions such as cancer screening, many potentially health-relevant digital technologies like pedometers or other wearable devices are bought on consumer markets. In terms of welfare economics, these applications can be regarded as private goods and services. In this case, it is up to the user to decide whether or not to download and use a digital health app based on their judgment of perceived costs and benefits. Only such private evaluation allows accounting for individual preferences.

On the other hand, such individual assessments of private, individual value can easily underestimate the costs of data disclosure (see chapter V6 "Ethical aligned design and how to implement it"). Also, it is far from easy to evaluate the effectiveness of a digital tool in a realistic, unbiased manner (see above). Therefore, regulation like data safety law is needed to ensure that digital goods do not incur harms that may not be perceived and thus not included in the private evaluation of cost-effectiveness. Also, it might be of value to make information on the effectiveness and cost-effectiveness of digital devices available easily intelligible. This ensures well-informed private decisions about the acquisition of DiPH technologies. While it could be seen as a task of researchers to take this aspect of transfer into account in their publication strategies, the provision of such information could also be left to the market, or be organized in a non-profit way like the Stiftung Warentest in Germany.

B.1.4.2. Coverage decisions using cost-effectiveness and cost-utility analysis

The need for publicly financed evaluations is more urgent if DiPH interventions are collectively funded by a national health service or a statutory health insurance system, thus turning these interventions into a public good. In this case, decision-makers need respective analyses to decide whether specific devices should be publicly reimbursed or not. Correspondingly, the standard context for which economic evaluation methods have been developed and are applied are coverage decisions made by healthcare and public health decision bodies. Respective bodies such as the English and Welsh National Institute for Health and Care Excellence (NICE) use cost-effectiveness analyses (CEA) and cost-utility analyses (CUA) as their standard tools.

CEA compares costs and a single health outcome . Examples of CEA in the context of DiPH are analyses of costs per

- kilogram weight loss (36),
- kilogram of fat loss (37, 38),
- metabolic equivalent hours of walking and leisure activity per week (39) or
- quitter in smoking cessation interventions (40).

The (incremental) cost-effectiveness ratio (ICER) then summarizes how much additional money has to be spent on improving the respected endpoint by one (marginal) unit.

CUA compares costs to a generic measure of health gain, which can combine single or multiple effects. Possible outcomes of economic evaluation are costs per quality-adjusted life year (QALY) or costs per disability-adjusted life year (DALYs) gained. QALYs combine the health-related quality of life (0 corresponds with death and 1 with full quality of life) and life years. They allow for comparing very different and similar interventions with varying effects on health. Most importantly, they allow comparisons between health technologies aiming at indications (35, 41). Among the 14 economic evaluations recently assessed by a systematic review of preventive Digital Public Health interventions (42), twelve analyzed costs per QALY.

Economic evaluation can incorporate data from different sources. The three paradigm cases are economic evaluations based on (i) clinical trials (43), (ii) observational data like routine data from sickness funds (44-46) and (iii) decision-analytic models, which can incorporate all sorts of data and are typically based on data from literature reviews (47). Even if observational studies appear highly relevant for evaluating DiPH interventions offered by sickness funds to their enrollees, own explorative searches conducted for this chapter mainly identified model- (see e.g. the studies in: 42) and trial-based (see e.g. the studies in: 48) health economic evaluations.

Though there are several CEA and CUA of digital health interventions (42, 48), knowledge is scarce compared to the numerous DiPH technologies which could be applied. For example, more than 100,000 commercial physical activity apps are currently available in the major app stores, but only a small number have undergone formal cost-effectiveness analysis (49). DiPH interventions, currently most frequently assessed by health economic evaluation, are web-based, text-message-based, and app-based to promote physical activity and weight loss, as well as interventions for smoking cessation (42).

Lange (42) reviewed economic evaluations that use decision-analytic modeling. While study-based economic evaluations are restricted to the short-term results of clinical trials, model-based analyses can more easily estimate costs and effects over longer time horizons. Accordingly, most model-based analyses have a medium or lifetime horizon, using various modeling approaches like Markov-, Multistate Life Table-, Discrete Event Simulation, or microsimulation models. Typically, the analyses estimated costs from the perspective of healthcare payers. Only two studies included societal costs in terms of productivity losses.

Regarding the final cost-effectiveness results, only two of the 14 studies Lange (2022) included reported that the expected costs of potentially avoided diseases exceed the intervention costs. Generally, the cost-effectiveness results are heterogeneous: the ICER of the included studies, which report cost per QALY, range between a min of –€ 1,616 and a max of € 114,211 (mean value of € 31,143 per QALY). Thus, a general statement on DiPH interventions' cost-effectiveness is impossible. The cost-effectiveness ratio has to be determined separately for each DiPH intervention as it depends on various issues like the type of intervention, the setting, and the target population.

Other reviews report on the cost-effectiveness of overall digital application areas such as mHealth (50), eHealth (51), both mHealth and eHealth (52) or specific groups such as the elderly (53) point towards the same direction.

B.1.4.3. Public policy decisions using cost-benefit analysis

DiPH interventions may also have consequences outside of healthcare, and decisions about their acquisition from scarce public budgets may be made by other than health and healthcare decision-makers. Moreover, digital interventions frequently have multiple benefits. Besides increasing health-related quality of life, for instance, an intervention that encourages commuting to work by bike rather than by private car can decrease presenteeism and absenteeism, and improve environmental impact or mental health and well-being.

Interventions which involve a diversity of benefits may better be susceptible to a cost-benefit analysis (CBA), which is not restricted to health-related endpoints but may include all kinds of consequences. To make them comparable, all outcomes of an intervention are expressed in monetary terms, thus allowing integration of all effects into one figure. Moreover, recommendations follow immediately from this kind of analysis: As long as the monetary values of the consequences are higher than the monetary costs of an intervention, it should be pursued according to CBA. In CEA and CUA, an additional assessment is necessary to decide whether the ICER is regarded as satisfactory. To estimate the monetary value of outcomes, willingness to pay (WTP) analyses are performed.

This might appear as if CBA is generally superior to CEA or CUA. However, it must be kept in mind that the two methodological approaches lean towards quite different normative conceptions of what a desirable allocation of scarce resources looks like (54). These conceptions are linked to the terms welfarism and extra-welfarism (55). Welfarists argue that the value of spending resources can only be determined by individuals and is best estimated by how much money individuals are willing to pay to receive this value. Extra-Welfarists argue that intersubjectively comparable measures of well-being, like capabilities, rather than individual preferences, should guide economic analysis (56). For a public health decision-maker whose primary concerns are health gains (and their distribution), CEA or CUA are likely to be the more appropriate approaches. In case a DiPH technology primarily provides other benefits than health gain, the acquisition of these technologies may better be left to the individuals' private valuation and market acquisition. CBA may be the more appropriate method for a policy maker outside the specific field of healthcare and public health, who has to account for very different dimensions of benefit.

Methods for estimating WTP are well established (57) and can also be applied to DiPH interventions. For example, WTP has been estimated as a weight loss maintenance intervention based on smart scales and text message support. The study revealed that the WTP per avoided percentage point of weight re-gain differed between £ 0.35 per month for users experienced with the intervention and £ 0.12 for the least experienced group. Also, highly educated and female respondents cared more about outcomes compared with costs (58). This stresses the importance of selecting adequate respondents for WTP surveys. Also, WTP is typically associated with income, so wealthier individuals' preferences bear a higher weight in WTP elicitation studies. This may be why a full CBA that compares benefits in terms of WTP with costs can rarely be identified for DiPH interventions. Further research would be necessary to provide better guidance on addressing these issues in the CBA of DiPH interventions.

The major challenges for conducting an economic evaluation of DiPH interventions do not lie in the cost side but somewhat in measuring effectiveness. Nevertheless, it is remarkable that economic evaluations, e.g., for prevention in the elderly (59) hardly account for the specific challenges the respective interventions raise for the measurement of effectiveness (see also: 42).

B.1.4.4. Company decisions using return on investment analysis

A fourth decision context relevant to the economic evaluation of DiPH interventions is the decision of companies that use digital technologies as investments in workplace health promotion (WHP). Like for other investments, managers are interested in such interventions' return on investment (ROI) (an idea that could also be relevant for publicly financed healthcare systems).

There are several studies comparing costs and cost savings of digital WHP interventions, like weight management (60), physical activity promotion (61), stress management (62) or combined programs (e.g. 63). Even if the analyses are sometimes labeled CBA, the benefits in these analyses typically consist of different types of direct and indirect costs like the costs of presenteeism, absenteeism, and saved medical expenditures due to avoided disease (60, 62). The latter are particularly relevant to public employers who co-fund their employees' healthcare.

It has to be noted that the considerations regarding assessing effectiveness above are also relevant for cost-effectiveness assessments: even if RCTs frequently lack external validity and suffer from too short time horizons, there are high associations between study types and the outcomes of ROI analyses of WHP interventions. A systematic review of 51 ROI studies of WHP programs showed a clear inverse relation between ROI and study quality. While the mean ROI of all WHP studies was 1.38, the higher the study quality, the lower was ROI. RCTs even exhibited a negative mean ROI (64).

B.1.4.5. Extending the perspective to include environmental benefits and harms

A general recommendation for the economic evaluation of publicly funded interventions is that the analyses should use the societal perspective, i.e., considering all costs and benefits from all members of society (65).

However, DiPH may not only produce (un)intended monetary costs borne by others than the public healthcare payer. They also consume resources that are not easily susceptible to monetarization (for example, use of the scarce absorption capacities of greenhouse gases

(GHGs)). Since 2006 health in all policies is a common demand, and there is good reason to demand climate in all policies now. Virtual services (e.g., telemedicine or virtual care) or DiPH interventions which encourage commuting by bike rather than by car could be assumed to avoid emissions. However, besides travel-related GHG emissions, these interventions also increase GHG emissions associated with the energy consumption of digital devices, servers, and networks, as well as indirect emissions related to the production of new devices.

Life-cycle assessment (LCA) is a well-developed methodology to analyze these emissions (66, 67). LCA provides a standardized technique to assess the environmental impacts of a product throughout its life cycle, i.e., from the extraction of raw materials through its production and use phase until its final disposal. There are two approaches to conducting LCAs: process-based and cost-based LCA. Process-based LCA uses a bottom-up approach in which information about all environmentally relevant material and energy flows associated with a product system are collected, and their environmental impacts are estimated based on approved models (68). Cost-based LCA pursues a top-down approach: using environmentally extended input-output tables, all environmental impacts of an economy (or different economies in multi-regional input-output models) are assigned to the economies' various industries. Using the Leontief inverse, emission factors per output for each industry can be calculated. By using the inverse, the whole supply chain is included. Using monetary values as units of calculation, these data allow estimating the environmental impact per Euro spent for products from a certain industry (69, 70).

There are different links between cost calculation in health economic evaluations and LCA. Following methodological standards of health economic evaluation, the analysis of costs should be based on the three steps of resource identification, measurement in physical units, and valuation (65). Since process-based LCA is based on data on resource consumption which are then valued (in terms of their environmental impacts, not in terms of their monetary values), there are theoretical similarities. Since bookkeeping data from cost type based accounts can also be used for cost-based LCA in healthcare (71), the methodological link between LCA and cost assessment is even more visible (for further information on the methodology, see Chapter IV.3.3 EPHO8: Assuring sustainable organizational structures and financing).

It should be noted that there are also links to the benefits side of economic evaluations. Generally, measuring effectiveness is a matter of balancing medical benefits and harms, and also QALYs allow aggregation of different positive and negative benefits. Likewise, ways could be found to include environmental advantages and disadvantages into the index of benefits in CUA, or they could be measured in terms of WTP in cost-benefit analysis. Further research is necessary on the appropriate integration of environmental concerns into economic evaluation, also on this aspect.

Given the discussion about climate change, using LCA to estimate the GHG footprint of DiPH would be of particular interest. However, assessing the environmental impacts, like the carbon footprint of new DiPH interventions, is still uncommon, so the published evidence is still sparse. One recent systematic review assessed the evidence on the carbon footprint of virtual care and identified 23 studies that claimed to estimate a carbon footprint. However, the existing studies barely met the methodological standards set by the different guidelines. Therefore, even if many studies concluded that virtual care interventions are carbon-saving, these results must be handled with care. This is mainly because they replace individual travel with less carbon-intensive teleconsultation (72). More research on this important topic and its connection to health economic evaluation is necessary. The current evidence suggests that studies in this field still has a long way to go until the application of methodological standards like in other fields of evidence-based medicine and public health is more widespread practice.

B.1.5. Conclusion

In the above reflections, we have dealt with two research questions: What is known about evaluating DiPH interventions, and how should evaluations of DiPH interventions be conducted? We have applied these questions to the evaluation's effectiveness and cost-effectiveness. Despite growing literature, hard evidence on effectiveness is scarce. Interestingly, the same is true for related areas, such as the effectiveness of digital nursing technologies (73, 74). So, the potential of effectiveness analyses is not fully used yet.

Concerning methodology and methods, a framework addressing the evaluation of DiPH interventions is now available (23). This may help ask the right questions in further assessments. Regarding study designs, it seems necessary to combine RCTs, which still present the gold standard for evaluation but are too slow for some purposes, with new evaluation forms such as CEEBIT, MOST, SMART, micro-randomized trials, and N-of-1 trials. As some of these forms are relatively new developments, more research is needed to understand what the contribution of these types of studies could be.

Reliable results from cost-effectiveness, cost-utility, and cost-benefit analyses are also still scarce. The range of ICERs in respective analyses is extensive. Interestingly, ROI analyses show a negative correlation between the resulting ROI and the study's methodological quality. So, RCTs give negative results, while studies with lower levels of evidence produce better results. This has to be considered when methodological recommendations are formulated. ROI studies seem to confirm the dilemma: Relying on RCTs bears the risk that evaluations take too much time to influence decision-making. Using other methods, on the other hand, might produce less reliable results. The careful combination of methods, thus, seems to be the only way to progress. As the importance of environmental consequences is growing, the consideration of these consequences in all policies seems inevitable. Future studies should, therefore, include respective aspects, such as the carbon footprint, of DiPH interventions. Given the yet under-investigated link between cost analysis and the analysis of environmental impact, this field will hopefully experience methodological development in the near future.

For effectiveness analysis and economic evaluation, it is essential to note that a significant share of DiPH interventions decisions rests with market actors. Users base their decisions on individual preferences. Nevertheless, effectiveness and efficiency analyses could contribute to better-informed decision-making. If DiPH interventions are financed collectively, effectiveness and efficiency analyses from a societal perspective are even more urgently needed.

B.1.6. Literature

1. Darmann-Finck I, Rothgang H, Zeeb H. „Digitalisierung und Gesundheitswissenschaften – White Paper Digital Public Health.“. Gesundheitswesen. 2020 Jul;82(7):620-2.

2. Zeeb H, Pigeot I, Schuz B. [Digital public health-an overview]. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz. 2020 Feb;63(2):137-44.

3. Knöppler K, Neisecke T, Nölke L. Digital-Health-Anwendungen für Bürger: Kontext, Typologie und Relevanz aus Public-Health-Perspektive; Entwicklung und Erprobung eines Klassifikationsverfahrens. Gütersloh: Bertelsmann; 2016.

4. Wienert J, Jahnel T, Maaß L. What are Digital Public Health Interventions? First Steps Toward a Definition and an Intervention Classification Framework. Journal of Medical Internet Research. 2022 Jun 28;24(6):e31921.

5. Ceci L. Number of mHealth apps available in the Apple App Store from 1st quarter 2015 to 3rd quarter 2022. Statista; 2022 [updated 2022; cited 2022 Nov 16]; Available from: https://www.statista.com/statistics/779910/health-apps-available-ios-worldwide/.

6. Tom-Aba D, Silenou BC, Doerrbecker J, Fourie C, Leitner C, Wahnschaffe M, et al. The Surveillance Outbreak Response Management and Analysis System (SORMAS): Digital Health Global Goods Maturity Assessment. JMIR Public Health Surveill. [Original Paper]. 2020;6(2):e15860.

7. Laranjo L, Ding D, Heleno B, Kocaballi B, Quiroz JC, Tong HL, et al. Do smartphone applications and activity trackers increase physical activity in adults? Systematic review, meta-analysis and metaregression. Br J Sports Med. 2021 Apr;55(8):422-32.

8. Tang MSS, Moore K, McGavigan A, Clark RA, Ganesan AN. Effectiveness of Wearable Trackers on Physical Activity in Healthy Adults: Systematic Review and Meta-Analysis of Randomized Controlled Trials. JMIR Mhealth Uhealth. 2020 Jul 22;8(7):e15576.

9. Davis FD. A Technology Acceptance Model for Empirically Testing New End-User Information Systems. Massachusetts Institute of Technology. 1985.

10. Davis FD. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly. 1989;13(3):319-39.

11. Venkatesh V, Davis FD. A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. Management Science. 2000;46(2):186-204.

12. Venkatesh V, Bala H. Technology Acceptance Model 3 and a Research Agenda on Interventions. Decision Sciences. 2008;39(2):273-315.

13. Venkatesh V, Thong J, Xu X. Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology. MIS Quarterly. 2012;36(1):157-78.

14. De Santis KK, Jahnel T, Matthias K, Mergenthal L, Al Khayyal H, Zeeb H. Evaluation of Digital Interventions for Physical Activity Promotion: Scoping Review. JMIR Public Health Surveill. 2022 May 23;8(5):e37820.

15. Heidel A, Hagist C. Potential Benefits and Risks Resulting From the Introduction of Health Apps and Wearables Into the German Statutory Health Care System: Scoping Review. JMIR Mhealth Uhealth. 2020 Sep 23;8(9):e16444.

16. Taj F, Klein MCA, van Halteren A. Digital Health Behavior Change Technology: Bibliometric and Scoping Review of Two Decades of Research. JMIR Mhealth Uhealth. 2019 Dec 13;7(12):e13311.

17. Muellmann S, Forberger S, Möllers T, Bröring E, Zeeb H, Pischke CR. Effectiveness of eHealth interventions for the promotion of physical activity in older adults: A systematic review. Prev Med. 2018 Mar;108:93-110.

18. Eze ND, Mateus C, Cravo Oliveira Hashiguchi T. Telemedicine in the OECD: An umbrella review of clinical and cost-effectiveness, patient experience and implementation. PloS one. 2020;15(8):e0237585.

19. De Santis KK, Mergenthal L, Christianson L, Zeeb H. Digital Technologies for Health Promotion and Disease Prevention in Older People: Protocol for a Scoping Review. JMIR Research Protocols. 2022 Jul 21;11(7):e37729.

20. Hrynyschyn R, Prediger C, Stock C, Helmer SM. Evaluation Methods Applied to Digital Health Interventions: What Is Being Used beyond Randomised Controlled Trials?-A Scoping Review. Int J Environ Res Public Health. 2022 Apr 25;19(9).

21. Saleem M, Kühne L, De Santis KK, Christianson L, Brand T, Busse H. Understanding Engagement Strategies in Digital Interventions for Mental Health Promotion: Scoping Review. JMIR Ment Health. 2021 Dec 20;8(12):e30000.

22. Unsworth H, Dillon B, Collinson L, Powell H, Salmon M, Oladapo T, et al. The NICE Evidence Standards Framework for digital health and care technologies - Developing and maintaining an innovative evidence framework with global impact. Digit Health. 2021 Jan-Dec;7:20552076211018617.

23. Pan CC, Pedros Barnils N, Jürgens D, Muellmann S, Janetzki S, Kolschen J, et al. Developing and assessing Digital Public Health Interventions: A comprehensive framework. 1st version.; 2022 [updated 2022; cited]; Available from: https://www.lsc-digital-public-health.de/forschung/framework.html.

24. Pham Q, Wiljer D, Cafazzo JA. Beyond the Randomized Controlled Trial: A Review of Alternatives in mHealth Clinical Trial Methods. JMIR Mhealth Uhealth. 2016 Sep 9;4(3):e107.

25. Gensorowsky D, Lampe D, Hasemann L, Düvel J, Greiner W. ["Alternative study designs" for the evaluation of digital health applications - a real alternative?]. Z Evid Fortbild Qual Gesundhwes. 2021 Apr;161:33-41.

26. Collins LM, Murphy SA, Strecher V. The multiphase optimization strategy (MOST) and the sequential multiple assignment randomized trial (SMART): new methods for more potent eHealth interventions. Am J Prev Med. 2007 May;32(5 Suppl):S112-8.

27. Mohr DC, Cheung K, Schueller SM, Hendricks Brown C, Duan N. Continuous evaluation of evolving behavioral intervention technologies. Am J Prev Med. 2013 Oct;45(4):517-23.

28. Klasnja P, Hekler EB, Shiffman S, Boruvka A, Almirall D, Tewari A, et al. Microrandomized trials: An experimental design for developing just-in-time adaptive interventions. Health Psychol. 2015 Dec;34s(0):1220-8.

29. Kravitz R, Duan N e, and the DEcIDE Methods Center N-of-1 Guidance Panel (Duan N EI, Gabler NB KH, Kravitz RL, Larson EB, Pace WD, Schmid CH, Sim I, Vohra S). Design and Implementation of N-of-1 Trials: A User’s Guide.; 2014 [updated 2014; cited August 2019]; Available from: https://effectivehealthcare.ahrq.gov/sites/default/files/pdf/n-1-trials_research-2014-5.pdf.

30. Kwasnicka D, Inauen J, Nieuwenboom W, Nurmi J, Schneider A, Short CE, et al. Challenges and solutions for N-of-1 design studies in health psychology. Health Psychol Rev. 2019 Jun;13(2):163-78.

31. Sniehotta FF, Presseau J, Hobbs N, Araújo-Soares V. Testing self-regulation interventions to increase walking using factorial randomized N-of-1 trials. Health Psychol. 2012 Nov;31(6):733-7.

32. Kumar S, Nilsen WJ, Abernethy A, Atienza A, Patrick K, Pavel M, et al. Mobile health technology evaluation: the mHealth evidence workshop. American Journal of Preventive Medicine. 2013 Aug;45(2):228-36.

33. Shiffman S, Stone AA, Hufford MR. Ecological momentary assessment. Annual Review of Clinical Psychology. 2008;4:1-32.

34. Abdolkhani R, Gray K, Borda A, DeSouza R. Quality Assurance of Health Wearables Data: Participatory Workshop on Barriers, Solutions, and Expectations. JMIR Mhealth Uhealth. [Original Paper]. 2020;8(1):e15329.

35. Drummond MF, Sculpher MJ, Claxton K, Stoddart GL, Torrance GW. Methods for the Economic Evaluation of Health Care Programmes. Oxford: Oxford: Oxford University Press; 2015.

36. Little P, Stuart B, Hobbs FR, Kelly J, Smith ER, Bradbury KJ, et al. Randomised controlled trial and economic analysis of an internet-based weight management programme: POWeR+ (Positive Online Weight Reduction). Health Technol Assess. 2017 Jan;21(4):1-62.

37. Chung LM, Law QP, Fong SS, Chung JW, Yuen PP. A cost-effectiveness analysis of teledietetics in short-, intermediate-, and long-term weight reduction. J Telemed Telecare. 2015 Jul;21(5):268-75.

38. van Wier MF, Dekkers JC, Bosmans JE, Heymans MW, Hendriksen IJ, Pronk NP, et al. Economic evaluation of a weight control program with e-mail and telephone counseling among overweight employees: a randomized controlled trial. Int J Behav Nutr Phys Act. 2012 Sep 11;9:112.

39. Maddison R, Pfaeffli L, Whittaker R, Stewart R, Kerr A, Jiang Y, et al. A mobile phone intervention increases physical activity in people with cardiovascular disease: Results from the HEART randomized controlled trial. Eur J Prev Cardiol. 2015 Jun;22(6):701-9.

40. Graham AL, Chang Y, Fang Y, Cobb NK, Tinkelman DS, Niaura RS, et al. Cost-effectiveness of internet and telephone treatment for smoking cessation: an economic evaluation of The iQUITT Study. Tobacco control. 2013 Nov;22(6):e11.

41. Brazier J, Ratcliffe J, Salomon JA, Tsuchiya A. Measuring and valuing health benefits for economic evaluation. 2 ed. New York Oxford: Oxford Univ. Pr.; 2017.

42. Lange O. Decision-analytic health economic evaluation of preventive digital public health interventions: A systematized review. Re-submission under review in: BMC Health Service Research [Earlier version available as preprint]

43. Ramsey S, Willke R, Briggs A, Brown R, Buxton M, Chawla A, et al. Good research practices for cost-effectiveness analysis alongside clinical trials: The ISPOR RCT-CEA Task Force report. Value in Health. 2005.

44. Berger ML, Dreyer N, Anderson F, Towse A, Sedrakyan A, Normand S-L. Prospective Observational Studies to Assess Comparative Effectiveness: The ISPOR Good Research Practices Task Force Report. Value Health. 2012;15(2):217-30.

45. Berger ML, Mamdani M, Atkins D, Johnson ML. Good research practices for comparative effectiveness research: defining, reporting and interpreting nonrandomized studies of treatment effects using secondary data sources: the ISPOR Good Research Practices for Retrospective Database Analysis Task Force Report--Part I. Value Health. 2009 Nov-Dec;12(8):1044-52.

46. Cox E, Martin BC, Van Staa T, Garbe E, Siebert U, Johnson ML. Good research practices for comparative effectiveness research: approaches to mitigate bias and confounding in the design of nonrandomized studies of treatment effects using secondary data sources: the International Society for Pharmacoeconomics and Outcomes Research Good Research Practices for Retrospective Database Analysis Task Force Report--Part II. Value Health. 2009 Nov-Dec;12(8):1053-61.

47. Briggs A, Claxton K, Sculpher M. Decision modelling for health economic evaluation. Reprint. ed. Oxford [u.a.]: Oxford Univ. Press; 2011.

48. Law L, Kelly JT, Savill H, Wallen MP, Hickman IJ, Erku D, et al. Cost-effectiveness of telehealth-delivered diet and exercise interventions: A systematic review. J Telemed Telecare. 2022 Feb 2:1357633X211070721.

49. Rondina R, Hong M, Sarma S, Mitchell M. Is it worth it? Cost-effectiveness analysis of a commercial physical activity app. BMC Public Health. 2021 Oct 27;21(1):1950.

50. Iribarren SJ, Cato K, Falzon L, Stone PW. What is the economic evidence for mHealth? A systematic review of economic evaluations of mHealth solutions. PloS one. 2017;12(2):e0170581.

51. Sanyal C, Stolee P, Juzwishin D, Husereau D. Economic evaluations of eHealth technologies: A systematic review. PloS one. 2018;13(6):e0198112.

52. de la Torre-Díez I, López-Coronado M, Vaca C, Aguado JS, de Castro C. Cost-utility and cost-effectiveness studies of telemedicine, electronic, and mobile health systems in the literature: a systematic review. Telemedicine journal and e-health : the official journal of the American Telemedicine Association. 2015 Feb;21(2):81-5.

53. Ghani Z, Jarl J, Berglund JS, Andersson M, Anderberg P. The Cost-Effectiveness of Mobile Health (mHealth) Interventions for Older Adults: Systematic Review. Int J Environ Res Public Health. [Review]. 2020 Aug;17(15):12.

54. Rogowski W. Ideale ohne Ideologie in der Ökonomik. Evidenzbasierte Verbindung positiver und normativer Ökonomik als Mittel der Ideologiekritik [Ideals sans Ideology in Economics. Evidence-based Conjunction of Positive and Normative Economics for Preventing Ideology]. Zeitschrift für Wirtschafts- und Unternehmensethik. 2022;23(1):57-92.

55. Brouwer WB, Culyer AJ, van Exel NJ, Rutten FF. Welfarism vs. extra-welfarism. J Health Econ. 2008 Nov 29;27(2):325–38.

56. Sen A. The Possibility of Social Choice. The American Economic Review. 1999;89(3):349-78.

57. MacIntosh E. Applied methods of cost-benefit analysis in health care. Reprint. ed. Oxford [u.a.]: Oxford University Press; 2010.

58. Mott DJ, Ternent L, Vale L. Do preferences differ based on respondent experience of a health issue and its treatment? A case study using a public health intervention. Eur J Health Econ. 2022 Jun 18.

59. Huter K, Dubas-Jakóbczyk K, Kocot E, Kissimova-Skarbek K, Rothgang H. Economic evaluation of health promotion interventions for older people: do applied economic studies meet the methodological challenges? Cost Effectiveness and Resource Allocation. 2018 2018/04/16;16(1):14.

60. Agrawal S, Wojtanowski AC, Tringali L, Foster GD, Finkelstein EA. Financial implications of New York City's weight management initiative. PloS one. 2021;16(2):e0246621.

61. Proper KI, de Bruyne MC, Hildebrandt VH, van der Beek AJ, Meerding WJ, van Mechelen W. Costs, benefits and effectiveness of worksite physical activity counseling from the employer's perspective. Scand J Work Environ Health. 2004 Feb;30(1):36-46.

62. Ebert DD, Kählke F, Buntrock C, Berking M, Smit F, Heber E, et al. A health economic outcome evaluation of an internet-based mobile-supported stress management intervention for employees. Scand J Work Environ Health. 2018 Mar 1;44(2):171-82.

63. McKnight T, Demuth JR, Wilson N, Leider JP, Knudson A. Assessing Effectiveness and Cost-Benefit of the Trinity Hospital Twin City Fit For Life Program for Weight Loss and Diabetes Prevention in a Rural Midwestern Town. Prev Chronic Dis. 2018 Aug 2;15:E98.

64. Baxter S, Sanderson K, Venn AJ, Blizzard CL, Palmer AJ. The relationship between return on investment and quality of study methodology in workplace health promotion programs. Am J Health Promot. 2014 Jul-Aug;28(6):347-63.

65. Drummond MF. Methods for the economic evaluation of health care programmes. 3rd ed. Oxford: Oxford Univ. Press; 2005.

66. DIN EN ISO 14040:2021-02. Environmental management - Life cycle assessment - Principles and framework (ISO 14040:2006 + Amd 1:2020); 2021 Contract No.: Document Number|.

67. DIN EN ISO 14044:2021-02. Environmental management - Life cycle assessment - Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020); 2021 Contract No.: Document Number|.

68. Matthews HSH, Chris T.; Matthews, Deanna H. Life Cycle Assessment: Quantitative Approaches for Decisions That Matter. 2018.

69. Minx JC, Wiedmann T, Wood R, Peters GP, Lenzen M, Owen A, et al. Input–output analysis and carbon footprinting: an overview of applications. Economic systems research. 2009;21(3):187-216.

70. Huang YA, Lenzen M, Weber CL, Murray J, Matthews HS. The role of input–output analysis for the screening of corporate carbon footprints. Economic Systems Research. 2009;21(3):217-42.

71. Zhang X, Albrecht K, Herget-Rosenthal S, Rogowski W. Estimation of carbon footprints for hospital care based on routine G-DRG accounting data in Germany: an application to acute decompensated heart failure. Journal of Industrial Ecology [in print]. 2022.

72. Lange O, Plath J, Dziggel TF, Karpa DF, Keil M, Becker T, et al. A Transparency Checklist for Carbon Footprint Calculations Applied within a Systematic Review of Virtual Care Interventions. Int J Environ Res Public Health. 2022;19(12):7474.

73. Huter K, Krick T, Domhoff D, Seibert K, Wolf-Ostermann K, Rothgang H. Effectiveness of Digital Technologies to Support Nursing Care: Results of a Scoping Review. Journal of Multidisciplinary Healthcare. 2020;13:1905-26.

74. Krick T, Huter K, Domhoff D, Schmidt A, Rothgang H, Wolf-Ostermann K. Digital technology and nursing care: a scoping review on acceptance, effectiveness and efficiency studies of informal and formal care technologies. BMC Health Services Research. 2019 Jun 20;19(1):400.

B.2. Module 2

Title:

Essential Public Health Operation 8: Assuring sustainable organizational structures and financing

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B.2.1. Summary

Essential Public Health Operation (EPHO) 8 requires the assurance of sustainable financing to provide efficient, effective, and responsive services. Pursuing this purpose requires evidence on how a digital public health (DiPH) intervention impacts on health, the environment, and scarce public health resources. Health economic evaluation provides a set of standards to generate this evidence. Based on the Consolidated Health Economic Evaluation Reporting Standards (CHEERS), this chapter discusses points to consider when evaluating (preventive) DiPH interventions. Specific issues arise, for example, from rapid technological change and the potential for long-term effects beyond the technological life cycle of single interventions. Also, which benefits and harms are to be considered in the economic evaluation depends on the decision maker, and very different decision makers may acquire DiPH technologies (e.g., private households, health systems, other public payers, and companies). As interventions may have an intersectoral impact, a broader perspective may be necessary. There is also a growing need to account for planetary boundaries of ecologically sustainable healthcare and public health. These issues can influence the results of an economic evaluation. Therefore, especially for DiPH interventions, it is important for decision-makers to reflect on assumptions and justify which areas are affected besides health.

Keywords

Economic evaluation, cost-utility, cost-effectiveness, cost–benefit, digital health, digital public health, climate change, life-cycle analysis

B.2.2. Introduction

Like any other public activity, public health operations have to account for limited resources. The purpose of EPHO 8 "is to ensure sustainable organizations and financing for public health to provide efficient, effective and responsive services. This entails developing services that are integrated, have minimal environmental impact with maximal health gain, and have sufficient funding for long-term planning. Sustainability in public health services will ensure that health is protected and promoted today and in the future" (1). Pursuing this purpose requires evidence of a service's impact on health, the environment, and limited public health budgets. This is our focus in the current chapter.

B.2.2.1. Generating evidence of sustainable financing for digital public health

In the policy debate, financial sustainability of health systems is frequently understood as a goal on its own right: to ensure balance between entitlements granted to the covered population and available funds (2: 1f.). However, this may lead to policy focus on achieving fiscal balance, ignoring the possible impact of cost containment policies on other health system goals like efficiency and equity (2: 5f.). We therefore follow Thomson, Foubister (2) by viewing financial sustainability as a constraint to be respected, rather than a goal on its own right.

Analyzing how to make (rational) decisions in the face of resource constraints can be seen as the definition of economics (3): generally, there are always more decision options that could be pursued than resources available which would be necessary to realize them. For example, in public health, there are always individuals that could benefit from more promotion of physical activity, dietary counselling or different genetic or other screening programs if more programs were offered or more efforts were made to tailor programs to individual preferences or to ensure that every individual receives the offer of existing programs. Besides medical, epidemiological, legal, or ethical considerations, one unavoidable question for wisely spending health resources is how to invest a given budget in a way to obtain as much benefit as possible, or of how to obtain some amount of benefit with as low cost as possible.

To meet health system objectives in the face of increasing costs and resource constraints, policy-makers have three options: increase the amount of funding; contain costs by reducing services; and increase efficiency by achieving more with existing resources (2: 7).

This chapter focuses on the third goal because digital technologies are associated with various promises to increase the effectiveness and efficiency of health services. For example, they may help to overcome spatial and temporal distances in monitoring health status and delivering health services, thereby reducing unnecessary transport, double diagnoses, avoidable diseases, and hospitalizations (see: 4: 102).

This topic is timely as reimbursement agencies are currently handling various novel digital interventions. In Germany, for example, digital prevention courses are made available at the cost or with co-payments from sickness funds, which have to provide verification of effectiveness from the "Prüfstelle Prävention" (Prevention Testing Center). Also, since the Digital Healthcare Act came into force in 2019, digital interventions such as weight-loss apps for obesity patients can be covered by statutory health insurance (5).

Generally, "digital intervention" and "digital technology" are very broad terms. Similarly, "digital public health" (DiPH) can be understood broadly as the digitalization of vertical public health functions encompassing all aspects of public health, such as health protection, health promotion, disease prevention, healthcare and preparedness for public health (6). However, the broader one's concept of DiPH, the more difficult it is to make specific statements on its contribution to the efficiency of health resource spending. Therefore, we follow the view of DiPH presented by Zeeb, Pigeot (7), who focus on population, health promotion, disease prevention, and public health topics such as equity. In this view, DiPH contrasts with other concepts like eHealth, mHealth, digital health, and telemedicine, which all focus on medicine and medical treatment. Although this chapter draws on some literature regarding those concepts, our focus is on (preventive) DiPH interventions such as smartphone and wearable interventions targeting weight loss.

To assess whether investing into new DiPH interventions is an efficient use of health systems' scarce resources, evidence of their cost-effectiveness is needed. This evidence can be generated by health economic evaluations. Depending on the type of evaluation, DiPH interventions can be compared to conventional alternatives in terms of costs per clinical health outcome (cost-effectiveness analysis); cost per generic health outcome, such as quality adjusted life-years (QALYs; cost–utility analysis); cost per disaggregated set of outcomes (cost–consequences analysis); or in monetary net benefit comparing costs to benefits measured in monetary values (cost–benefit analysis) (8). Chapter II.6 Evaluation in this handbook briefly overviews evidence of the effectiveness and cost-effectiveness of DiPH interventions. In this chapter, we focus on the methods of assessing their cost-effectiveness.

DiPH interventions impact on not only the scarce financial resources of health systems but also the scarce environmental resources used as inputs and the limited capacities to absorb emissions from health systems. These impacts may be desirable – for example, if a digital program for promoting physical activity reduces the number of individuals commuting by car to sports facilities, or if it reduces the number of hospital admissions and their associated carbon footprints (cf. 9). However, the impacts may also be detrimental to the environment. For example, owing to the rebound effect, increases in material or energy efficiency of digital devices may be more than offset by the direct and embedded energy and material use of the growing number of devices and applications (10-12). Therefore, we cover how to account for environmental impact in the economic assessment of DiPH efficiency.

B.2.2.2. Existing knowledge and targeted gaps

Various articles describe methodological challenges in the economic evaluation of digital healthcare. However, they focus on digital health (e.g., 13, 14, 15), digital mental health (e.g., 16), or telemedicine (e.g., 17, 18, 19). To our knowledge, there is no systematized account of methodological challenges in the economic evaluation of (preventive) DiPH interventions. According to Weatherly, Drummond (20), standard techniques are limited for preventive interventions. The authors cite four reasons: first, costs and benefits are connected to populations instead of individuals; second, as costs and benefits are typically wider for public health, an intersectoral approach may be needed to comprehensively identify them; third, typically used approaches for measuring and valuing health benefits (e.g., QALYs) may fail to capture the intended effects; and fourth, standard methods of health economic evaluation may not sufficiently account for health inequalities, which are a particular feature of many public health interventions (20).

Therefore, this chapter aims to discuss relevant aspects for the economic evaluation of (preventive) DiPH interventions, considering both issues of digitalization and the specific challenges of assessing interventions for prevention and health promotion.

A central reference on how to conduct health economic evaluations transparently is the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) (21). CHEERS aims to ensure that all types of economic evaluation are interpretable and useful for decision-making by specifying which details should be included (21). We use CHEERS for structuring methodological challenges in the economic evaluation of DiPH interventions. Following this structure, Section 2 will elaborate on the primary public health challenges regarding economic evaluation and then address points to consider in evaluation.

In environmental evaluations of digital technologies, it is necessary to capture not only the environmental impacts associated with the technology's use – e.g., energy use and associated carbon dioxide (CO_2) emissions – but also those associated with its resource use, production, transport, and disposal. In short, a life-cycle perspective is required.

Broadly, there are two methodological approaches that serve this purpose. First, process-based life-cycle assessment (LCA) requires the identification of all processes and systems used to generate the intended outcome of a product throughout its life cycle. Data on all relevant material and energy flows within these processes is collected in a life-cycle inventory and used to build a life-cycle model. Subsequently, the environmental impacts of these flows are analyzed, usually based on approved models such as ReCiPe or TRACI. The final phase of process-based LCAs is the interpretation of results, including sensitivity analyses and discussion of limitations. Methodological standards for conducting process-based LCAs are provided by the International Organization of Standardization's (ISO) norms 14040 and 14044 (22).

Second, environmentally extended input-output life-cycle assessment (EEIO-LCA) estimates environmental impacts based on a top-down approach, in contrast to the bottom-up approach of process-based LCA. The environmental impacts of an economy are allocated to its different industry sectors through input-output tables documenting the material and product exchanges between industry sectors. Extending these accounts of product flows in monetary values by environmental satellite accounts allows the calculation of emission factors per end product of the economy's industries – i.e., estimates of environmental impacts like CO_2 emissions per euro spent on products from a given industry. Multi-regional EEIO models allow the inclusion of environmental impacts caused by production processes outside a national economy (23, 24). While the estimates of environmental impacts from EEIO-LCA are less accurate than process-based LCA, they are easier to obtain. This is because health sector accounting frameworks provide standards for reporting costs per cost type. Frequently, these cost types (e.g., drugs or food) can be associated with industries (e.g. pharmaceutical or food industry) for which emission factors are available – so that environmental impacts like carbon footprint can be estimated by multiplying costs from bookkeeping data with readily available emission factors (see e.g. 25).

While standards for conducting process-based or EEIO-LCA are available, the reporting standards are far less developed than those for other methods relevant to public health, such as health economic evaluations (for an example dedicated to carbon footprint, see: 9). Also, it is an open question whether and how the assessment of environmental scarcities by LCA can be integrated into health economic evaluations of DiPH. Environmental goals could be included on the effect side of economic evaluations, by developing some aggregate measure of benefit that includes environmental benefit. Alternatively, environmental costs could be included on the cost side, extending the perspective of costs to environmental ones. In addition to reporting points to consider in evaluating DiPH interventions using standard health economic methods, the following section will elaborate on how environmental impacts might be integrated into the analysis.

B.2.3. Assuring sustainable financing & considering environmental impacts

CHEERS provides a benchmark for transparency in its guidance on what to report in health economic evaluations. Its 28 items can also be used as a transparency checklist in systematic reviews of health economic evaluations (26). In the following, methodological challenges are discussed with reference to each item in sequence.

B.2.3.1 Title, abstract, and introduction

CHEERS requires that the title identifies the study as an economic evaluation and specifies the interventions being compared (item #1). Next, the abstract should describe the interventions (item #2), and the introduction should present the study question and its relevance for policy practice (item #3) (21). These criteria may appear rather generic for evaluations of DiPH interventions. It should be kept in mind, however, that reviews tracking the evidence in this field typically rely on information in the titles and abstracts to decide whether to include a study. Therefore, to ensure proper evidence synthesis, it is important to explicitly state the digital component early in the study report.

While standardized definitions of various digital health applications have been proposed, there is still a lack of standardized terminology for digital health interventions (DHI) (27). Until such a generally agreed upon terminology has been developed, it would be desirable if the aim of the intervention is stated alongside with a description of the technology by which it is delivered (for example: A cost-effectiveness analysis of a weight-loss intervention delivered by mobile app and wearable vs. face-to-face meetings).

B.2.3.2 Health economic analysis plan

CHEERS item #4 requires an indication of whether a health economic analysis plan (HEAP) was developed (21). HEAPs are used as study protocols and describe trials, parameters, and assumptions before an economic evaluation is conducted. Standardization of HEAPs is a new requirement for health economic evaluations. For trial-based economic evaluations, the authors of CHEERS (Husereau et al. 2022) referred to a recent Delphi study determined that 58 items should be included (28), clustered into the following subsections: administrative information, trial introduction & background, economic approach / overview, economic data collection & management, economic data analyses, modeling, reporting / publishing, and appendixes.

However, as Chapter II.6 Evaluation explains, standard randomized controlled trials (RCTs) may not be the best approach for establishing evidence on the effectiveness of DiPH interventions. A more flexible approach that can integrate different types of evidence is decision-analytic modeling. However, it is still unclear how HEAPs should be designed for model-based health economic evaluations. Also, study protocols are common practice in study-based economic evaluations (e.g., to describe an RCT) but not for model-based economic evaluations. Generally, it appears possible to state the research question, justify the choice of perspective and the included effects and costs, and scientifically discuss a decision-analytic model before the analysis is conducted. However, decision-analytic models should incorporate the best available evidence, and new evidence may be published during the modeling work, especially in the dynamic field of DiPH.

B.2.3.3 Study population & setting

The choice of study population to which a DiPH intervention is offered typically has various effects on effectiveness and cost-effectiveness. Thus, CHEERS requires detailed description of the characteristics of the study population (item #5). Particularly for preventive public health interventions, the target population can be heterogeneous (29). Therefore, besides the study population, relevant subgroups should be identified. CHEERS also requires the provision of contextual information on setting and location that may impact on the results (item #6 in: 30).

The selection of study population and subgroups always depends on the decision problem and other parameters (e.g., setting and location). It should be noted that the study population does not always correspond to the target population. For example, a weight-loss app may be considered very effective based on study results obtained from its use with obese individuals, but this result may not be transferable to the general population. This difference in effects may relate to not only absolute effects (e.g., if a cardiovascular drug prevents more myocardial infarctions in high-risk than low-risk patients) but also relative effects like risk reduction if perception, understanding, and reaction to the digital stimulus differ across subgroups (e.g., if diagnosed patients feel more affected by their disease than do undiagnosed persons and thus are more adherent to prevention (16)). Unlike specific clinical interventions like bowel cancer screening, DiPH interventions like smartphone apps are available to all. For a smartphone app aiming to help the user lose weight (and reduce their risk of chronic diseases), the effect could be higher in a group of obese or overweight persons. Additionally, the use of a DiPH intervention may mutually complement another treatment – for example, if a physician gives a diabetes patient detailed instructions on how to use a nutrition app, whereas an individual user in the general population lacks access to this information.

B.2.3.4 Comparators

CHEERS item #7 ("Comparator") requires a study to cautiously report the interventions or strategies being compared (21). Given the complexity of digital technologies, it is not easy to describe a DiPH intervention in a standardized manner. Different frameworks offer guidance on effectively describing an intervention or comparator.

For example, for the Template for the Intervention Description and Replication (TIDieR), a specific variant was developed to improve the reporting of research and ultimately maximize the potential for reproducing and implementing telehealth interventions (TiDieR-telehealth) (31). TIDieR-telehealth requires reporting of the intervention name, rationale, used materials (e.g., software), procedures (e.g., remote delivery), intervention provider, type of location, number of times the intervention was delivered and over what period, details of any personalization or modification, and various other details.

While TIDieR-telehealth is a generic framework for telehealth interventions only, the mERA checklist (32) provides reporting guidance for mHealth interventions that could be adapted to describe digital aspects of the intervention and comparator in more detail. For example, mERA distinguishes between intervention delivery (e.g., SMS or face-to-face) and intervention content. Further, it requires the reporting of available infrastructure (electricity or connectivity), technology platform (soft- and hardware), and interoperability (integration with existing health information systems). These technical aspects could be further investigated in environmental analyses by considering how much additional resources are necessary to implement the evaluated intervention.

One further framework is CONSORT-EHEALTH, a list of items for reporting web-based and mobile health interventions (33). It was developed specifically for use in publishing RCTs and contains 17 subitems deemed essential and 35 subitems deemed highly recommended. Especially in DiPH, with countless apps available, these frameworks for describing an intervention can increase reproducibility.

While several frameworks are available to support detailed description of interventions, there remains the question of what constitutes the DiPH intervention's comparator. For non-digital public health interventions, examples of comparators are no program, standard care, or best alternative therapy (29). Kolasa et al. (34) recommend that the value of a digital intervention should be expressed in comparison to the current standard of care. However, any comparator group is exposed to the multitude of other available digital interventions, making it unclear what constitutes "digital standard care" or "best alternative therapy". In particular, if a smartphone app intervention is compared to business-as-usual, various other apps are potentially freely available. The difference in effect between doing nothing and the intervention might be much larger than that between the intervention and business-as-usual. Also, clinical-trial participants in the "business-as-usual" group can access numerous other digital interventions (35). Therefore, the comparator choice may need to be specific to digital interventions.

Gomes, Murray (36) propose considering "digital and non-digital comparators and whether DHI replaces or complements existing technology" (36). "For mHealth solutions without a comparator, a model-based full economic evaluation may be possible, drawing on primary data on the program's implementation costs" (37). Moreover, Gomes, Murray (36) propose a comparator for interventions of an area where other digital interventions are implemented and dominate digital care. First, the intervention could be compared to an alternative way of implementing the same DHI (36). For example, Jones (38), Mizdrak (39) and Cleghorn (40) conduct model-based economic evaluations and evaluate the promotion of various existing apps. Second, the intervention could be compared to a competing DiPH (36). For weight-loss interventions, many manufacturers of wearables or apps offer a similar function, so economic evaluation could compare against competing alternatives. Third, an appropriate comparator might be an "existing technology that the DHI is replacing" (36). For instance, a physical-activity and weight-loss intervention may involve a new sensor that gives feedback on user behavior by measuring the pulse, replacing generic feedback.

However, given the rapidity of technological development, effectiveness data may be lacking for some comparators. Therefore, model-based economic evaluation may need to use a comparator with the best available evidence, rather than the most appropriate comparator.

Also, the distinction between digital and non-digital comparators can also pose difficulties, as the digital aspects can only be considered as one part of the intervention. This is also illustrated by the fact that McNamee, Murray (41) related digital interventions to the concept of complex interventions. Finally, there are various intermediate stages en route to a full digital intervention.

B.2.3.5 Perspective

CHEERS item #8 requires that the perspective is stated, i.e., the viewpoint from which the analysis is conducted. This viewpoint is the basis for determining which costs and benefits should be included (29).

As indicated in Chapters Framework (Domain "Costs and Economics") and Evaluation (Section "Evaluation of cost-effectiveness") in this handbook, stating the perspective is more complex for DiPH than for standard healthcare interventions. Suppose one wants to evaluate a new device tracking physical activity which is intended to improve the user's pleasure and performance when engaging in physical exercise like running, with the ultimate aims of improving their health status and lowering their risk of diabetes, stroke, and cardiovascular diseases. For evaluating a medical intervention like a new cancer drug, it is straightforward to adopt a healthcare payer perspective. However, various perspectives may be relevant for (preventive) DiPH interventions:

- First, a private individual perspective might be appropriate because DiPH interventions (e.g., apps promoting physical activity) are frequently offered to individuals for free or devices (e.g., activity trackers) are frequently acquired by individuals based on their preferences. Therefore, evaluations could plausibly include costs to private budgets and benefits of satisfying individual preferences.
- Second, DiPH interventions (sometimes even the same ones offered to private customers) may be covered by healthcare payers. In this case, a payer perspective would likely to be considered appropriate, focused on health benefits and healthcare costs.
- Third, DiPH interventions may also be covered by other public payers like federal, state, or local governments as part of a digitalization strategy. In such cases, measuring both costs and benefits in monetary units might frequently be most appropriate to enable cost-effectiveness comparison against very different alternative uses of scarce public budgets beyond the health system.
- Fourth, DiPH interventions may also be funded by companies for their employees. In such cases, economic evaluation will likely to be conducted in terms of return on investment from a company perspective.

Formal health economic evaluations are generally conducted by healthcare and public health payers. Consequently, health outcomes are likely to be a key focus when evaluating DiPH interventions. Nevertheless, it appears important not to restrict the cost perspective to the narrow health(care) payer perspective but to incorporate a societal viewpoint. One reason is that a societal perspective has been recommended specifically for preventive interventions (29), which is an important aspect of our concept of DiPH. There have also been calls to include a societal perspective in digital health frameworks so as to account for costs outside the healthcare sector (36). Especially for preventive DiPH interventions, spillover effects within households (particularly behavioral changes) could be better captured through a societal perspective (41), as could productivity losses (see e.g. 42, 43).

Increasingly visible ecological scarcities, such as the limited capacity of the atmosphere to absorb CO2, may necessitate further broadening the perspective of the evaluation to include environmental issues. One increasingly important concept that aims to bridge health and environmental considerations is “planetary health,” summarized by (44) as “the health of human civilisation and the state of the natural systems on which it depends.” Taking a planetary rather than a societal perspective in evaluating a DiPH intervention (e.g., a new fitness tracker) would thus involve a) including its environmental impacts as intermediate endpoints in the estimation of intervention effects; or b) including its impacts on environmental scarcity in the assessment of resources, potentially as external or intangible costs.

B.2.3.6 Time horizon

CHEERS item #9 requires the study’s time horizon to be stated and justified. A distinction needs to be made between the time horizon of the intervention, that of effectiveness studies, and the analytical time horizon. For example, a digital weight-loss intervention with a duration of three months could be assessed in a follow-up study that estimates the effects after one year. This follow-up may conclude that the digital intervention decreases the risk of developing diabetes or heart disease, which are potentially long-term chronic diseases. Therefore, even if the intervention lasted only a few months, it seems reasonable to choose a broader analytical time horizon.

Particularly for preventive interventions, a lifelong time horizon typically appears ideal because present costs and future benefits are involved (45). If the chosen time horizon were too short, the results would be distorted by missing not only relevant effects but also, especially for DiPH, the expected costs to maintain an intervention. For example, a digital food diary needs updates to remain functional as operating systems change on the used device.

This call for long time horizons contrasts with the short technology cycles of DiPH interventions. Rapid technological progress constantly renews the ways interventions are offered. For example, while web-based applications were more common a few years ago, they have now been largely replaced by smartphone applications. Individuals get used to digital devices, so constant innovation may even be required for a digital prevention program to maintain users' adherence. Given the rapid technological development of DiPH interventions, there is a lack of data for respective technologies over longer time periods. Consequently, it is unclear how long-term adherence and effectiveness can be achieved and should be modeled in economic evaluation. It is likely that assumptions must be made that need validation or testing in sensitivity analyses (16).

B.2.3.7. Discount rate

Related to the choice of time horizon, CHEERS item #10 requires reporting of the discount rate, relevant only for time horizons longer than one year.

The concept of time preference describes the extent to which an equal amount of benefit is valued higher in the present than in the future. It is typically assumed that individuals prefer health benefits received today over future health benefits (29). Consequently, economic evaluation discounts interventions' costs and benefits. Given that the effects of preventive public health interventions potentially occur over a long time horizon, the choice of discount rate can be expected to have a large impact as higher discount rates diminish future costs and effects in the cost-effectiveness estimate (45).

However, the last few years have seen particularly rapid technological development in sensors, smartphones, and other tech through which digital health services are delivered. This leads to a conundrum: While time preference suggests that an investment should be made now rather than in the future, technology dynamics suggest that the same amount (in real terms) would generate significantly more effects if invested in the future rather than now. There may, thus, be a trade-off between accounting for time preference and accounting for rapid technological change.

B.2.3.8. Selection, measurement, and valuation of outcomes

CHEERS items #10, #11, and #12 respectively require description of which outcomes are used, how they are used and how there are valued. Depending on the intervention purpose, various outcomes could be considered. As pointed out in the section on perspective (see Section 2.5), relevant outcomes can include what individuals value for whatever reason, standard health outcomes used in health economic evaluation, or outcomes that matter to other payers, such as workplace health effects for employers.

Even within health systems, DiPH interventions may be used for various purposes. The NICE Evidence Standards Framework for digital health and care technologies (46) contains 10 functional categories on three levels (tier A: System impact; tier B: Understanding and communicating; and tier C: Interventions). These categories describe the purposes of digital health technologies most frequently funded by the health system. Many are also relevant for DiPH as conceptualized in this chapter – e.g., in tier A, system services like the COVID-19 warning app for preventive behavior; in tier B, health diaries using fitness wearables for general health monitoring; or in tier C, preventive behavior change. Following the framework, each tier is associated with specific evidence standards, with higher evidence requirements for tier C. For digital health technologies in tier C, only those in the functional categories of treatment, active monitoring, calculating, or diagnosing require evidence of effectiveness from RCTs with clinical outcomes. The effectiveness of preventive-behavior or self-management interventions should be established by experimental or quasi-experimental comparative studies, preferably with patient-reported or other relevant outcomes using validated tools but possibly also with outcomes like physiological measures, user satisfaction and engagement, or care process indicators like admissions and appointments. For other functions, the framework requires evidence of aspects like user acceptability or credibility with health and social care professionals, without the need to conduct RCTs (46).

For economic analysis, NICE recommends cost–utility analysis following the institute's standard methodology. If the benefit cannot be estimated in terms of QALYs, cost–consequence analysis is recommended, also following NICE standards. In addition, budget impact analysis is recommended (46).

There are a number of value-assessment guidelines for digital health interventions; they typically incorporate different aspects like organizational impact, data security, or technical considerations (34). NICE recommends aggregating all relevant outcomes in terms of QALYs, or reporting them in a disaggregated manner in a cost–consequences analysis. By contrast, Kolasa et al. (34) recommend establishing a multi-criteria score representing the clinical, organizational, behavioral, and technical performance of a digital health solution in the context of its implementation (47).

Given the requirement of EPHO 8 to account for ecological sustainability, environmental effects could be integrated into the outcomes when economically evaluating DiPH interventions, either by listing them among the effects in cost–consequences analysis or by integrating them into some new multi-attribute value or utility score. However, because EPHO

8 requires minimizing environmental impacts, it might be more straightforward to integrate them among the costs. This approach would recognize that the environment represents scarce ecological resources used for providing the benefits of DiPH. The next section elaborates further.

B.2.3.9. Resources and costs

CHEERS item #14 ("Measurement and valuation of resources and costs") requires the description of how costs were valued. Relatedly, item #15 stipulates that the currency, price date, and conversion method should be reported.

Besides the typical categories of costs and cost savings of public health programs (29), which can be cross-sectoral (20), various other types of costs might need to be considered in the economic evaluation of DiPH interventions. These costs can broadly be structured by whether they accrue for intervention content or delivery, and whether they accrue before or during and after the intervention (see Figure 5).

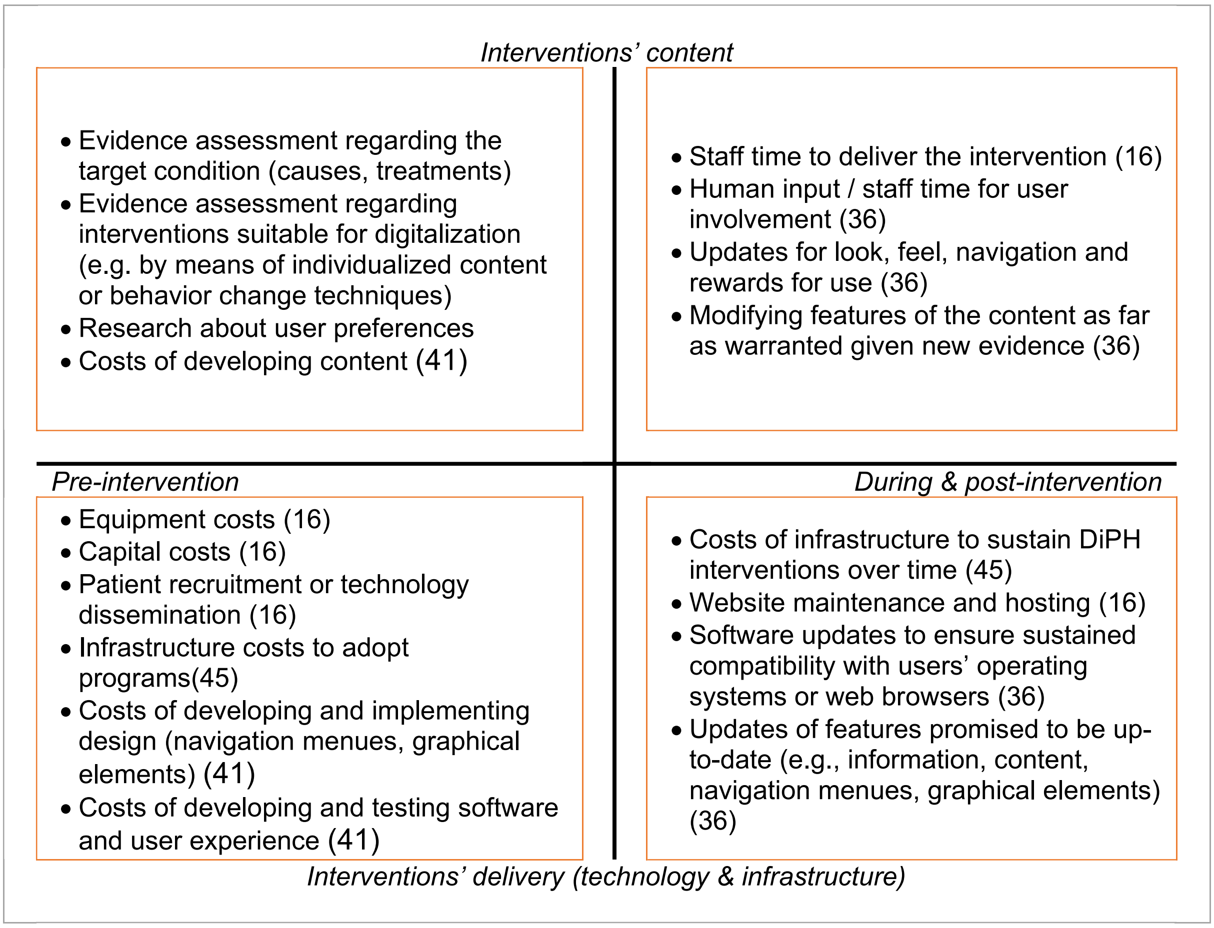

Figure 5: Potentially relevant costs specific for DiPH interventions

One cost feature of DiPH interventions is the need for frequent updates, whether to adapt design and manageability, maintain compatibility with operating systems, or implement new features (36). As McNamee, Murray (41) point out, digital interventions that are not updated cease to function.

As Following Gomes, and Murray (36) point out, digital interventions are also characterized by high fixed and low variable costs because the incremental costs for additional users are close to zero. Consequently, studies with small sample sizes would result in overestimation of mean costs per user (36). A counter-balancing assumption is that DiPH interventions are typically more effective if recipients receive human support to ensure they apply the digital technology as intended (36, 48). Any associated personnel costs need to be taken into account. However, this needs to be seen in the context of the rapid technological change. Digital interventions have already evolved from mere advice on websites to individualized feedback using sensors. The fast pace of technological change and the time required to evaluate health services in general may result in studies being outdated and effectiveness underestimated, and new technologies may successfully substitute for human input.

The mERA checklist (32) includes various single components that can play a role in digital interventions. For example, if interoperability is emphasized, additional costs may be incurred and additional standards may need to be set by health legislation. Also, data security may have a high impact on costs. These and other requirements such as ethical concerns should be considered to investigate whether meeting them impacts on the costs of DiPH interventions.

As pointed out above, DiPH interventions consumer not only scarce financial resources of health systems but also scarce natural resources like the planetary capacity to absorb greenhouse gas (GHG) emissions. There are different methodological links between cost analysis in health economic evaluation and environmental assessment. The need to report quantities and prices of resources separately was more prominent in early guidelines for reporting economic evaluations (49) but is still required by CHEERS (30, 50). If all resources used are transparently listed and quantified in both physical units and prices, this provides a highly valuable starting point for LCAs. In particular, lists by cost type (e.g., server infrastructure or electrical energy) can easily be translated into lists of respective environmental impacts if the costs can be linked to industry sectors for which cost-based emission factors are available from EEIO-LCA databases (for an example of carbon footprint in hospital care, see: 25).

Where environmental impacts are not adequately priced (which can be assumed as typical), they constitute external costs that ought to be included in the analysis from a planetary cost perspective. However, further specification is needed on which environmental impacts should be included and whether and how they should be aggregated, converted into monetary terms, and reported. Until such guidance is issued on health economic evaluation in general or for DiPH in particular, one approach could be to select some core impacts, such as GHG emissions, and list them in a disaggregated manner in addition to the intervention's monetary costs.

B.2.3.10. Model, analytics, heterogeneity, and uncertainty

For model-based economic evaluations, CHEERS item #16 requires the report to describe which model is used. This is supplemented by item #17, which requires description of all methods for analyzing, transforming, extrapolating, and validating the model. CHEERS item #18 additionally requires transparency on the methods used to analyze differences between subgroups, while item #20 calls for transparency on any sources of uncertainty.

For evaluating DiPH interventions, model-based economic evaluation and, consequently, CHEERS item #16 appear particularly relevant, because modeling does have advantages (51) which are applicable to DiPH. First, decision-analytic modeling allows estimation of long-term effects and cost-effectiveness, which would otherwise only be possible through costly long-term studies unlikely to be financially feasible for digital technology manufacturers (in contrast to pharmaceutical companies). Second, model-based analyses can more easily integrate different types of data such as effectiveness data from n=1 trials and other new trial designs unsuitable for the cost questionnaires used in standard RCTs. Third, modeling studies make it easier to account for technology dynamics by integrating data on the most recent versions of DiPH interventions or modeling respective scenarios (given that, after a long-time study, the DiPH technology used is very likely to be outdated already).

Model-based economic evaluations of DiPH interventions must also cope with particularly high structural uncertainty, given that rapid development may change technologies and care patterns. It is also difficult to account for parameter uncertainty: DiPH studies may in fact assess quite different interventions, so pooled estimates may be misleading because variance is due to technological differences, not uncertainty of outcomes. Therefore, there is a particular need for transparency about the modeling methods; ideally, open source models are required to allow early estimation of the cost-effectiveness of new DiPH interventions.

Another important question is at what stage a model-based economic evaluation is appropriate. The literature suggests that the appropriate evaluation method depends on the maturity of a health intervention: in earlier stages, feasibility, usability, and efficacy are most relevant; in intermediate maturity effectiveness; and when scaling, cost-effectiveness and implementation research is needed to assess the extent to which an intervention can be sustainably integrated into a given context, including policies and practices (32).

As for other highly dynamic technologies for which cost-effectiveness cannot be easily estimated before market entry, new forms of coverage with evidence development and evidence generation alongside use in public health practice (52, 53) could be important complements to decision-analytic modeling of DiPH. This is because model-based estimates of cost-effectiveness need validation to ensure the efficient use of scarce resources funding a DiPH intervention, in comparison to other available digital and analog public health interventions.

As individualized interventions are possible in DiPH, the role of heterogeneity and the need to establish evidence about ever smaller subgroups assume high importance (theoretically up to an n=1 level of heterogeneity). However, this area needs further research.

B.2.3.11. Distributional effects and stakeholder engagement

CHEERS item #19 requires description of the distribution of impacts across different individuals or how priority populations are accounted for, and so is especially important for evaluating DiPH interventions. These considerations may also bear on CHEERS item #21, which requires transparency about the involvement in study design of patients or any other affected stakeholders.

Generally for prevention interventions, the determinants of health and disease are especially important, as addressing them may be necessary to prevent ill health. As far as these determinants are distributed unequally across socioeconomic groups (and thus a matter of chance, not individual choice), resulting health inequalities give rise to equity concerns that ought to be accounted for in the design and (economic) evaluation of DiPH interventions.

A widely used framework for understanding determinants of health and health inequalities is the socioecological “rainbow” model. In this model, Dahlgren et a. (54) organize these determinants on five hierarchical levels: a) general socioeconomic, cultural, and environmental conditions; b) living and working conditions; c) social and community networks; d) individual lifestyle factors; and e) the individual-level stable characteristics like age and sex (54: 20).

In the economic evaluation of DiPH interventions, it is important to consider that these five layers are permeated by digital technologies and that health inequalities increasingly depend on digital determinants (55). Generally, the probability of individuals adhering to behavioral advice in prevention or screening programs strongly influences a program’s effectiveness and cost-effectiveness (for an example of secondary prevention, see: 56, 57). When assessing DiPH interventions, it should be considered that factors like adherence can be influenced by relevant developments on these five layers. For example, inequalities in the sustained use of a wearable device and smartphone app to promote physical activity can be influenced by lower internet bandwidth in deprived areas (living and working conditions level), differential exposure to online misinformation (social and community networks level), or unequal distribution of digitally mediated sedentary behavior (individual lifestyle factors level) (see: 55, Fig. 1).

There are different methodological approaches to incorporate equity concerns into health economic evaluation (58). In circumstances as complex as described in the previous paragraph, equity impact analysis may be particularly relevant as it allows assessing costs and effects using equity-relevant variables – e.g., by assessing the additional costs and effects of providing some digital infrastructure or device not typically available in a deprived group to equalize adherence to the digital intervention.

The move to involve patients, the public, and other stakeholders in designing economic evaluations is still in its infancy but represents a potentially important step toward enhancing the quality and acceptance of health economic research (50). Particularly for evaluating DiPH interventions, the need to appropriately account for the complexity of distributional effects may justify exploring new ways of involving relevant stakeholder groups in evaluation design.

B.2.3.12. Results & discussion

Under the heading "Results," CHEERS items #22–25 require the presentation of information on all analytical input parameters, a summary of key results (such as the uncertainty of analytical values, discount rate, or time horizon), and details of the effect of engagement with patients or stakeholders. Here, the same points to consider for the economic evaluation of DiPH interventions apply as those discussed in the sections above.

Next, item #26 ("Discussion") requires critical assessment of the limitations, any ethical or equity considerations not captured, and what effects these may have on patients, policy, or practice. Given the points to consider presented above, limitations are likely an important aspect of the economic evaluation of DiPH interventions. Even with the ambition to provide comprehensive analysis, it is unlikely that every type of cost or outcome can be captured: there may be limited available data on all nuances of costs and benefits, or insufficient room to address all possible sources of equity concerns. It may be neither possible nor necessary to incorporate all relevant aspects in the estimation of average costs per health outcome.

Finally, items #27 and #28 respectively require the reporting of funding sources and conflicts of interest (30). As for other (public) health interventions, sufficient public funding must be allocated to evaluation to ensure unbiased estimates of the relative merits of different DiPH options currently available to health systems.

B.2.3.13. Adopting a planetary perspective

While CHEERS provides valuable guidelines on points to consider in the economic evaluation of DiPH interventions, it naturally omits reporting items not yet standard in health economic evaluations – in particular, the planetary perspective.

Properly reporting results from process-based or EEIO-LCAs requires more than merely presenting emission factors for cost types and the results of multiplying them with cost values. LCA should be explicit about reasons for excluding certain processes from the analysis (e.g., the negligible additional energy consumption of a smartphone during use in a DiPH intervention); the temporal, geographical, and technological representativeness of data used in the analysis (e.g., assessing whether the GHG emission factors assumed for electrical energy consumption correspond with the energy mix in the intervention region); or ideally report environmental impacts per life-cycle phase (e.g., to estimate what proportions of GHG emissions arise during the program itself, the production phase of its components such as activity trackers, or the phase of their disposal) (9, 59). No guidance currently exists on which of these LCA items can appropriately be identified alongside CHEERS items and which may need to be reported separately to provide a transparent assessment from a planetary benefits or costs perspective. Further research is necessary to fill this research gap.

B.2.4. Conclusion

DiPH is a field characterized by highly dynamic technologies. While web-based and browser-based applications were once considered innovative, DiPH interventions today entail smartphone applications, wearables, and mobile devices. Therefore, economic evaluations have to cope with the fact that available effectiveness studies frequently incorporate yesterday's technologies.

Perspective appears particularly important in the economic evaluation of DiPH interventions, which can incur private benefits, health effects relevant to healthcare and public health payers, or effects relevant to companies. Which costs and benefits are relevant, and consequently which evaluation method is most appropriate, needs to be determined more explicitly than is necessary, for example, in the economic evaluation of pharmaceuticals.

Specific issues in the cost assessment of DiPH interventions include the need for continuous updates to maintain compatibility with computer or smartphone operating systems. Economic evaluation might consider update costs and the restricted time horizon of intervention effects. Another key issue is that high fixed costs may be incurred during development, particularly for software-based interventions, but the incremental costs of including additional users are close to zero.

In the face of climate change, how might economic evaluations of DiPH interventions account for the planetary boundaries of ecologically sustainable public health? Besides drawing on standard methods to list a number of points to consider in evaluating DiPH interventions, this chapter offers first thoughts on how to incorporate a planetary perspective.

B.2.5. Literature

1. WHO Regional Office for Europe. EPHO8: Assuring sustainable organisational structures and financing 2022 [Available from: https://www.euro.who.int/en/health-topics/Health-systems/public-health-services/policy/the-10-essential-public-health-operations/epho8-assuring-sustainable-organisational-structures-and-financing.

2. Thomson S, Foubister T, Figueras J, Kutzin J, Permanand G, Bryndová L. Addressing financial sustainability in health systems. Policy summary prepared for the Czech European Union Presidency Ministerial Conference on the Financial Sustainability of Health Systems in Europe. Copenhagen, Denmark: World Health Organization, Regional Office for Europe; 2009.

3. Rogowski WH, Elsner W. How economics can help mitigate climate change - a critical review and conceptual analysis. Bremen Papers on Economics & Innovation [Internet]. 2021.

4. Leppert F, Greiner W. Finanzierung und Evaluation von eHealth-Anwendungen [Funding and evaluation of ehealth applications]. In: Fischer F, Krämer A, editors. eHealth in Deutschland Anforderungen und Potenziale innovativer Versorgungsstrukturen [ehealth in Germany Requirements and potential of innovative structures of care]. Berlin Heidelberg: Springer-Verlag GmbH; 2016.

5. Lantzsch H, Eckhardt H, Campione A, Busse R, Henschke C. Digital health applications and the fast-track pathway to public health coverage in Germany: challenges and opportunities based on first results. BMC Health Serv Res. 2022;22(1):1182.

6. Essential public health functions, health systems and health security: developing conceptual clarity and a WHO roadmap for action. Geneva: World Health Organization; 2018.

7. Zeeb H, Pigeot I, Schüz B, Leibniz-WissenschaftsCampus Digital Public Health B. [Digital public health-an overview]. Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz. 2020;63(2):137-44.

8. Drummond MF. Methods for the economic evaluation of health care programmes. 3. ed. Oxford [u.a.]: Oxford Univ. Press; 2007. XV, 379 S. p.

9. Lange O, Plath J, Dziggel TF, Karpa DF, Keil M, Becker T, et al. A Transparency Checklist for Carbon Footprint Calculations Applied within a Systematic Review of Virtual Care Interventions. International Journal of Environmental Research and Public Health. 2022;19(7474):1-14.

10. Galvin R. The ICT/electronics question: Structural change and the rebound effect. Ecol Econ. 2015;120:23-31.

11. Court V, Sorrell S. Digitalisation of goods: a systematic review of the determinants and magnitude of the impacts on energy consumption. Environmental Research Letters. 2020;15(4).

12. Zhou XY, Zhou DQ, Wang QW, Su B. How information and communication technology drives carbon emissions: A sector-level analysis for China. Energy Econ. 2019;81:380-92.

13. Kwee A, Teo ZL, Ting DSW. Digital health in medicine: Important considerations in evaluating health economic analysis. Lancet Reg Health West Pac. 2022;23:100476.

14. Gomes M, Murray E, Raftery J. Economic Evaluation of Digital Health Interventions: Methodological Issues and Recommendations for Practice. Pharmacoeconomics. 2022.

15. Babigumira JB, Dolan S, Shade S, Puttkammer N, Bale J, Tolentino H, et al. Applied Economic Evaluation of Digital Health Interventions 2021 [

16. Jankovic D, Bojke L, Marshall D, Saramago Goncalves P, Churchill R, Melton H, et al. Systematic Review and Critique of Methods for Economic Evaluation of Digital Mental Health Interventions. Applied health economics and health policy. 2020.

17. Dávalos ME, French MT, Burdick AE, Simmons SC. Economic evaluation of telemedicine: review of the literature and research guidelines for benefit-cost analysis. Telemed J E Health. 2009;15(10):933-48.

18. Bergmo TS. Approaches to economic evaluation in telemedicine. J Telemed Telecare. 2012;18(4):181-4.

19. Rojas SV, Gagnon MP. A Systematic Review of the Key Indicators for Assessing Telehomecare Cost-Effectiveness. Telemed J E Health. 2008;14(9):896-904.

20. Weatherly H, Drummond M, Claxton K, Cookson R, Ferguson B, Godfrey C, et al. Methods for assessing the cost-effectiveness of public health interventions: Key challenges and recommendations. Health Policy. 2009;93(2):85-92.

21. Husereau D, Drummond M, Augustovski F, de Bekker-Grob E, Briggs AH, Carswell C, et al. Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) statement: updated reporting guidance for health economic evaluations. BMJ. 2022;376:e067975.

22. Matthews HSH, Chris T.; Matthews, Deanna H. Life Cycle Assessment: Quantitative Approaches for Decisions That Matter2018.

23. Minx JC, Wiedmann T, Wood R, Peters GP, Lenzen M, Owen A, et al. Input–output analysis and carbon footprinting: an overview of applications. Economic systems research. 2009;21(3):187-216.

24. Huang YA, Lenzen M, Weber CL, Murray J, Matthews HS. The role of input–output analysis for the screening of corporate carbon footprints. Economic Systems Research. 2009;21(3):217-42.

25. Zhang X, Albrecht K, Herget-Rosenthal S, Rogowski W. Estimation of carbon footprints for hospital care based on routine G-DRG accounting data in Germany: an application to acute decompensated heart failure. Journal of Industrial Ecology [in print]. 2022.

26. Lange O. Decision-analytic health economic evaluation of preventive digital public health interventions: A systematized review. Re-submission under review in: BMC Health Service Research [Earlier version available as preprint]

27. Burrell A, Zrubka Z, Champion A, Zah V, Vinuesa L, Holtorf AP, et al. How Useful Are Digital Health Terms for Outcomes Research? An ISPOR Special Interest Group Report. Value Health. 2022;25(9):1469-79.

28. Thorn JC, Davies CF, Brookes ST, Noble SM, Dritsaki M, Gray E, et al. Content of Health Economics Analysis Plans (HEAPs) for Trial-Based Economic Evaluations: Expert Delphi Consensus Survey. Value Health. 2021;24(4):539-47.

29. Haddix AC, Teutsch SM, Corso PS. Prevention effectiveness: a guide to decision analysis and economic evaluation: Oxford University Press; 2002.

30. Husereau D, Drummond M, Augustovski F, de Bekker-Grob E, Briggs AH, Carswell C, et al. Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) Statement: Updated Reporting Guidance for Health Economic Evaluations. Value Health. 2022;25(1):3-9.

31. Rhon DI, Fritz JM, Kerns RD, McGeary DD, Coleman BC, Farrokhi S, et al. TIDieR-telehealth: precision in reporting of telehealth interventions used in clinical trials - unique

considerations for the Template for the Intervention Description and Replication (TIDieR) checklist. BMC Med Res Methodol. 2022;22(1):161.

32. Agarwal S, LeFevre AE, Lee J, L'Engle K, Mehl G, Sinha C, et al. Guidelines for reporting of health interventions using mobile phones: mobile health (mHealth) evidence reporting and assessment (mERA) checklist. BMJ. 2016;352:i1174.

33. Eysenbach G. CONSORT-EHEALTH: improving and standardizing evaluation reports of Web-based and mobile health interventions. J Med Internet Res. 2011;13(4):e126.

34. Kolasa K, Kozinski G. How to Value Digital Health Interventions? A Systematic Literature Review. Int J Environ Res Public Health. 2020;17(6).

35. Murray E, Hekler EB, Andersson G, Collins LM, Doherty A, Hollis C, et al. Evaluating Digital Health Interventions: Key Questions and Approaches. Am J Prev Med. 2016;51(5):843-51.

36. Gomes M, Murray E, Raftery J. Economic Evaluation of Digital Health Interventions: Methodological Issues and Recommendations for Practice. Pharmacoeconomics. 2022:1-12.

37. LeFevre A, Cabrera-Escobar MA, Mohan D, Eriksen J, Rogers D, Neo Parsons A, et al. Forecasting the Value for Money of Mobile Maternal Health Information Messages on Improving Utilization of Maternal and Child Health Services in Gauteng, South Africa: Cost-Effectiveness Analysis. JMIR Mhealth Uhealth. 2018;6(7):e153.

38. Jones AC, Grout L, Wilson N, Nghiem N, Cleghorn C. The Cost-effectiveness of a Mass Media Campaign to Promote Smartphone Apps for Weight Loss: Updated Modeling Study. JMIR Form Res. 2022;6(4):e29291.

39. Mizdrak A, Telfer K, Direito A, Cobiac LJ, Blakely T, Cleghorn CL, et al. Health Gain, Cost Impacts, and Cost-Effectiveness of a Mass Media Campaign to Promote Smartphone Apps for Physical Activity: Modeling Study. J Med Internet Res. 2020;22(6):e18014.

40. Cleghorn C, Wilson N, Nair N, Kvizhinadze G, Nghiem N, McLeod M, et al. Health Benefits and Cost-Effectiveness From Promoting Smartphone Apps for Weight Loss: Multistate Life Table Modeling. JMIR Mhealth and Uhealth. 2019;7(1):13.

41. McNamee P, Murray E, Kelly MP, Bojke L, Chilcott J, Fischer A, et al. Designing and Undertaking a Health Economics Study of Digital Health Interventions. Am J Prev Med. 2016;51(5):852-60.

42. Cobos-Campos R, Mar J, Apinaniz A, de Lafuente AS, Parraza N, Aizpuru F, et al. Cost-effectiveness analysis of text messaging to support health advice for smoking cessation. Cost Eff Resour Alloc. 2021;19(1):9.

43. Song M, Kanaoka H. Effectiveness of mobile application for menstrual management of working women in Japan: randomized controlled trial and medical economic evaluation. J Med Econ. 2018;21(11):1131-8.

44. Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, de Souza Dias BF, et al. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation-Lancet Commission on planetary health. Lancet. 2015;386(10007):1973-2028.

45. Crowley DM, Dodge KA, Barnett WS, Corso P, Duffy S, Graham P, et al. Standards of Evidence for Conducting and Reporting Economic Evaluations in Prevention Science. Prevention Science. 2018;19(3):366-90.

46. Unsworth H, Dillon B, Collinson L, Powell H, Salmon M, Oladapo T, et al. The NICE Evidence Standards Framework for digital health and care technologies - Developing and

maintaining an innovative evidence framework with global impact. Digit Health. 2021;7:20552076211018617.

47. Kolasa K, Kozinski G. How to Value Digital Health Interventions? A Systematic Literature Review. Int J Environ Res Public Health. 2020;17(6):2119.

48. Yardley L, Spring BJ, Riper H, Morrison LG, Crane DH, Curtis K, et al. Understanding and Promoting Effective Engagement With Digital Behavior Change Interventions. Am J Prev Med. 2016;51(5):833-42.

49. Drummond MF, Jefferson TO. Guidelines for authors and peer reviewers of economic submissions to the BMJ. The BMJ Economic Evaluation Working Party. BMJ. 1996;313(7052):275-83.

50. Husereau D, Drummond M, Augustovski F, de Bekker-Grob E, Briggs AH, Carswell C, et al. Consolidated Health Economic Evaluation Reporting Standards (CHEERS) 2022 Explanation and Elaboration: A Report of the ISPOR CHEERS II Good Practices Task Force. Value Health. 2022;25(1):10-31.

51. Briggs A, Sculpher M, Claxton K. Decision modelling for health economic evaluation. Oxford: Oxford Univ. Press; 2006.

52. Brandes A, Schwarzkopf L, Rogowski WH. Using Claims Data for Evidence Generation in Managed Entry Agreements. Int J Technol Assess Health Care. 2016;32(1-2):69-77.

53. Rogowski W, John J, Ijzerman M. Translational Health Economics. In: Scheffler RM, editor. World Scientific Handbook of Global Health Economics and Public Policy. 3: World Scientific; 2016.

54. Dahlgren G, Whitehead M. European strategies for tackling

social inequalities in health: levelling up part 2. Copenhagen, DK: WHO Regional Office for Europe; 2007.

55. Jahnel T, Dassow HH, Gerhardus A, Schuz B. The digital rainbow: Digital determinants of health inequities. Digit Health. 2022;8:20552076221129093.

56. Rogowski WH. The cost-effectiveness of screening for hereditary hemochromatosis in Germany: a remodeling study. Med Decis Making. 2009;29(2):224-38.

57. Rogowski WH, Grosse SD, Meyer E, John J, Palmer S. Die Nutzung von Informationswertanalysen in Entscheidungen über angewandte Forschung. Der Fall des genetischen Screenings auf Hämochromatose in Deutschland. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz. 2012;55(5):700-9.

58. Cookson R, Mirelman AJ, Griffin S, Asaria M, Dawkins B, Norheim OF, et al. Using Cost-Effectiveness Analysis to Address Health Equity Concerns. Value Health. 2017;20(2):206-12.

59. Keil M, Viere T, Helms K, Rogowski W. The impact of switching from single-use to reusable healthcare products: A transparency checklist and systematic review of life-cycle assessments. Accepted for publication in the European Journal of Public Health.

B.3. Module 3

Title:

Health economic evaluation of preventive digital public health interventions using decision-analytic modelling: A systematized review

Authors:

Oliver Lange

Publication

The publication is accessible at Lange, O. Health economic evaluation of preventive digital public health interventions using decision-analytic modelling: a systematized review. BMC Health Serv Res 23, 268 (2023). https://doi.org/10.1186/s12913-023-09280-3

Note

At the time the dissertation was submitted as an examination version, Module 3 was still under review after resubmission. After the recommendation of the examination board and the permission of the Dr. rer. pol. doctoral committee, the version was updated. Consequently, for the publication of the dissertation, the resubmitted (not yet accepted) version was replaced with the link (see above) to the accepted and printed version.

B.4. Module 4

Title:

A Transparency Checklist for Carbon Footprint Calculations Applied within a Systematic Review of Virtual Care Interventions

Authors:

Oliver Lange, Julian Plath, Timo F. Dziggel, David F. Karpa, Mattis Keil, Tom Becker and Wolf H. Rogowski

Publication

The publication is accessible at Lange, O.; Plath, J.; Dziggel, T.F.; Karpa, D.F.; Keil, M.; Becker, T.; Rogowski, W.H. A Transparency Checklist for Carbon Footprint Calculations Applied within a Systematic Review of Virtual Care Interventions. Int. J. Environ. Res. Public Health 2022, 19, 7474. https://doi.org/10.3390/ijerph19127474

Declarations

Declaration of authorship by candidate

M1 – Book chapter “Evaluation”

The book chapter was a collaboration of a total of 7 authors. OL and WR drafted a first outline and the basic idea for the chapter. OL took care of the administration of the work process. The rest of the work was separated into the respective sub-chapters. SM, KDS PB, WB wrote the sub-chapter "Evaluation of Effectiveness". The chapter "Evaluation of cost-effectiveness" was assigned to WR and OL. OL wrote a draft of an earlier version of the sub-chapter "Cost-effectiveness" and the introduction. WR and HR revised the sub-chapter of the manuscript extensively. The examples mentioned in this sub-chapter "cost-effectiveness" were identified through literature search and data collection by OL. WR and HR revised and harmonized the entire manuscript.

M2 – Book Chapter “EPHO8”

The book chapter EPHO8 (M3) was conceptualised and methodologically elaborated by OL and WR. Literature search, data collection, data analysis and interpretation were done mostly by OL. OL wrote most of the draft regarding health economic evaluation, WR wrote most of the section on LCA and CF. In an earlier version, OL revised the chapter based on comments from WR. The final revision was done by WR.

M3 – Systematized review of economic evaluation using decision analytical modelling

OL was the sole author and conceptualized the review, developed the methodology, did the literature search, data collection, data analysis and interpretation. Laura Birg and Walter Tietgen conducted double independent abstract screening. As part of the supervision of the dissertation, WR made comments and suggestions for improving the manuscript.

M4 – Carbon footprint of virtual care

OL has shared first authorship with JP. The manuscript was written in the context of a research seminar. OL and WR taught methods of systematic reviews, while JP, DK, TB, TD wrote drafts based on the findings. OL and WR critically reviewed the drafts and suggested improvements until an overall draft was produced. Not in the original search, but when the search was updated OL and MK did literature search, data collection, analysis together. Generally, OL was responsible for the systematic review process and WR was largely responsible for the CF assessment catalogue. After an earlier revision of the manuscript by WR and JP, OL revised the whole manuscript and prepared it for submission. OL made a revision after a minor revision requested by the journal and resubmitted.

Summarizing table

	Module 1 (Introduction and sub-chapter cost-effectiveness)	Module 2	Module 3	Module 4
Conceptualization	Partly	Partly	Fully	Partly
(Project administration)	Partly	Mostly	Fully	Fully
(Methodology)	Not applicable	Mostly	Fully	Partly
Literature Search	Partly	Fully	Fully	Partly
Data collection	Partly	Fully	Fully	Partly
Data analysis	Partly	Mostly	Fully	Partly
Discussion and interpretation	No	Mostly	Fully	Partly
(Visualization)	Not applicable	Fully	Fully	Partly
Manuscript preparation	Partly	Mostly	Fully	Partly
Manuscript revision	No	Mostly	Fully	Mostly

Place, date

Oliver Lange

Declaration of authorship by supervisor

As the supervisor of the doctoral candidate, I hereby certify that the statement of the candidate's contribution to each manuscript stated under "Declaration of authorship by candidate" is accurate.

Place, date

Wolf Rogowski

Declaration of originality

I hereby declare, that …

- … it is my original work and it is conducted without unauthorized assistance
- … only the referenced sources and aids were used
- … I made due references to all published or unpublished work either quoted or used as the basis for ideas

I permit, that this dissertation to be checked for plagiarism using appropriate software.

Place, date	Oliver Lange