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Capturing the value of vaccination within health technology assessment and health economics: Country analysis and priority value concepts

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ABSTRACT

Background: A value of vaccination framework for economic evaluation (EE) identified unique value concepts for the broad benefits vaccination provides to individuals, society, healthcare systems and national economies. The objectives of this paper were to work with experts in developed countries to objectively identify three priority concepts to extend current EE.

Methods: The previously developed classification of value concepts in vaccination distinguished 18 concepts, categorised as conventional payer and societal perspective concepts and novel broader societal concepts. Their inclusion in current EE guidelines was assessed. Experts identified eight criteria relevant to decision-making and measurement feasibility, which were weighted and used to score each concept. The relative ranking of concepts by importance and the gaps in guidelines were used to identify three priority concepts on which to focus immediate efforts to extend EE.

Results: The EE guidelines review highlighted differences across countries and between guidelines and practice. Conventional payer perspective concepts (e.g., individual and societal health gains and medical costs) were generally included, while gaps were evident for conventional societal perspective concepts (e.g., family/caregiver health and economic gains). Few novel broader societal benefits were considered, and only in *ad hoc* cases. The top-three concepts for near-term consideration: macroeconomic gains (e.g., benefiting the economy, tourism), social equity and ethics (e.g., equal distribution of health outcomes, reduced health/financial equity gaps) and health systems strengthening, resilience and security (e.g., efficiency gains, reduced disruption, increased capacity).

Conclusions: Gaps, inconsistencies and limited assessment of vaccination value in EE can lead to differences in policy and vaccination access. The three priority concepts identified provide a feasible approach for capturing VoV more broadly in the near-term. Robust methods for measuring and valuing these concepts in future assessments will help strengthen the evidence used to inform decisions, improving access to vaccines that are demonstrably good value for money from society's point of view.

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1. Introduction

Vaccination continues to play a key role in health, preventing severe disease and mortality globally, as well as contributing to the prevention of antimicrobial resistance [1]. By preventing illness, the burden on health and social care systems is reduced, thereby making vaccination one of the most cost-effective interventions available [1,2]. There is also a reduced burden on patients and caregivers, leading to productivity gains for society as a whole [3]. In addition, by reducing transmission, vaccination programmes can protect unvaccinated people in the community through herd protection [3].

One of the important lessons learnt from the COVID-19 pandemic is that vaccinations produce much broader benefits, which should be taken into consideration when assessing their value to society [4]. For example, national immunisation programmes can significantly contribute to an efficient, resilient and secure healthcare system by reducing hospitalisations and intensive care stays, provide peace of mind by lowering the risk of infection, and confer macroeconomic benefits e.g., impacting productivity, education, the national economy and tourism [3,5].

National bodies (e.g., National Immunization Technical Advisory Groups [NITAGs]) that advise governments on inclusion of vaccines in national immunisation programmes and on their reimbursement often use value criteria that differ across countries. In some countries NITAGs are solely responsible for the assessment and recommendation for NIP inclusion which automatically triggers funding/reimbursement. However, in other countries where NITAGs make NIP recommendations but a different body decides on reimbursement, different value criteria may apply within a single country. For example, the majority of NITAGs consider public health impact and clinical and economic criteria as key decision making factors, while health technology assessment (HTA) bodies often only consider clinical and economic factors for reimbursement decisions [6].

Among countries that include economic evaluation in their HTA, the cost-effectiveness analysis (CEA) of vaccines typically adopts a 'healthcare payer' perspective on relevant costs and costs averted, and only considers a narrow range of incremental benefits e.g., the vaccinated individuals' health gains and healthcare costs, with only a few countries considering wider societal benefits such as patient/caregiver productivity gains and herd immunity benefits [7–9]. The outcomes of these analyses affect access to vaccinations and can be binding in some countries [6].

Different value considerations that complement or modify the results of conventional CEA have been introduced following deliberation in special cases e.g., in the CEA for the meningococcal B vaccine in the United Kingdom (UK), to better account for disease severity or societal preferences [10,11] and, in the consideration of reduced discount rates in the CEA for human papillomavirus vaccination of boys in the UK [12]. This process, however, is not always transparent and not standardised. Similarly in France, although not included in formal CEA, different value judgements, such as consideration of socio-economic inequities or gender discrimination, were amongst the motives for expanding meningococcal B vaccination to all newborns [13] and HPV vaccination to boys [14]. A comparison of NITAG processes and decision-making in France versus the Netherlands regarding seasonal influenza vaccination showed that a lack of standard evidence appraisal methods led to reliance on expert judgement and, ultimately, different influenza policies in these countries, despite similar evidence [15]. These variable considerations, along with other factors such as differing epidemiology, might contribute to the fact that vaccination policies vary within or across countries, despite infectious diseases having no borders.

Previous comparisons of NITAGs in developed countries have focussed on the heterogeneity and lack of transparency in processes and decision-making criteria [6,16,17]. A comprehensive overview of a broad range of vaccination value concepts assessed at the national level by NITAGs and/or HTA bodies conducting CEA has not, to the best of our knowledge, been previously published. There is a need to understand how different countries currently value vaccination benefits, and a need for a framework able to describe the full value of vaccination (VoV) in future HTAs. Introducing a broader value scope in HTAs using CEA (HTA/CEA) processes will help national bodies to consider their current VoV and potential future expansions. As it may not be feasible to capture the full VoV at present, objective and transparent methods are required to identify and prioritise key additional value concepts for vaccines that can be pragmatically implemented in the next 5 to 10 years. This study focusses on developed countries with established HTA systems, in order to compare current approaches and allow transferability of new approaches, thereby allowing decision makers across countries to draw on a common set of broader value concepts in their decision making.

The overall aim of the study, published as a three-part series, is to develop an overview of how the value of non-pandemic vaccines can be more broadly captured in HTA, with a pragmatic focus on identifying those concepts of value where methods are available or can readily be developed to support implementation in EE in the near to midterm future. The development of an HTA-focussed VoV framework is published in part 1 in this journal by [18]. The objectives of part 2 in this paper were 1) to assess which of the framework's value concepts are already included in country HTAs, to gain a common understanding of what the current definition of the VoV is, and 2) to objectively prioritise key concepts to expand the notion of VoV, with country expert engagement. Finally, the pragmatic steps for including the identified priority concepts in HTA/CEA will be published in part 3.

2. Methodology

The HTA-relevant VoV framework development with its 18 unique value concepts (part 1) is described in Beck et al. [18]. The framework is divided into three broad categories or 'dimensions', each including subcategories or value 'concepts' under which specific examples or 'elements' of value are described. Dimension I includes conventional concepts included in HTA/CEA of vaccines from a payer perspective. Dimension II includes conventional concepts included in vaccine HTA/CEA from a societal perspective. Dimension III includes a broad range of novel extended/wider societal perspective concepts (Supplementary Fig. S1 and Table S1). In this paper, we refer generally to CEA (rather than distinguishing between cost-effectiveness and cost-utility analyses) while acknowledging that, in many countries, cost-utility analysis is the preferred form of CEA.

Fig. 1 summarises the study phases and objectives.

To determine if and how the 18 value concepts from the VoV framework are currently considered, guidelines for HTA or health economic assessment of vaccines were reviewed from the countries included in the study i.e., Australia [19,20], France [21–23], Germany [24,25], the Netherlands [26–28], Spain [29], the UK [30,31] and the US [32,33]. These countries have well-established HTA systems representative of key healthcare system archetypes for high-income countries globally.

In the guidelines assessment, concepts were categorised as 1) included / well acknowledged; 2) partly included / accounted for only in some circumstances; 3) included in deliberative processes / mentioned as potentially relevant; or 4) not included. Experts in vaccine HTA/CEA from the countries represented (who were

involved in the framework development and throughout the entire study) were consulted to validate the guideline concept mapping exercise and to provide insights into potential differences between guidelines and current practice.

During discussions, the experts agreed that a stepwise approach was needed to include broader value elements into HTA/CEA. To prioritise key VoV concepts that should be targeted for inclusion in HTA in the near to midterm future, a ranking and scoring exercise was performed using weighted criteria to assess each concept. During a brainstorming session, the experts identified a set of potential criteria that could be used to prioritise VoV concepts for future consideration in HTA/CEA: five criteria for 'relevance to decision-making' and three criteria for 'feasibility of measurement' (Fig. 2).

Experts in each country first performed an absolute ranking of concepts by overall importance. They then assigned a country-specific relative weight to each of the eight criteria i.e., a number of points adding up to 100 across all eight criteria. The VoV concepts were then scored by each expert according to the eight prioritisation criteria shown in Fig. 2, with scores ranging from 1 ("Not at all") to 5 ("Strong yes"). For example, a concept which could be quantified using existing methods (criterion 'Availability/ability to develop measures') would receive a score 5 and be ranked higher than a concept for which a method was not in place. The combination of these scores and the relative weights resulted in a total score per concept that was used to produce a relative ranking of all concepts (from highest to lowest aggregate score per concept).

Finally, with the goal of capturing a broader value of vaccination in HTA/CEA in the near to midterm future, during an Advisory Board meeting, the experts selected the top-three key concepts based on the relative ranking and the lack of current inclusion in country HTAs according to the country mapping. The experts also assessed the measurement methods and evidence needs for the other concepts belonging to Dimension III that will help inform long-term research.

3. Results

3.1. Mapping of VoV concepts considered in HTA guidelines

Fig. 3 shows how the 18 VoV framework concepts described in [18] are included in HTA guidelines in each participating country (using colours), along with any differences in practice highlighted by the experts (using symbols).

In Dimension I, according to guidelines, concepts in green are well-acknowledged and included. Based on expert feedback, however, societal health gains beyond vaccinated individuals (e.g., health gains to wider society from reductions in transmission and herd immunity or outbreak control/preparedness) are not generally considered in the US, and do not include outbreak control/preparedness in the Netherlands. In France, reduction in transmission was considered when extending HPV vaccination to boys, but not in a CEA [14]. There are also limitations regarding the inclusion of direct and indirect benefits i.e., efficacy derived from clinical trials is used as a proxy for real-world effectiveness but may overestimate the benefit; while herd immunity is unlikely to be available before widespread introduction and may be underestimated at the time of the EE. Both uncertainties can be adjusted for in sensitivity analyses.

In Dimension II, caregiver economic gains are reported in countries such as Germany and the Netherlands, but quality of life gains in caregivers are not commonly included. Health-related productivity gains from vaccination (e.g., reduction in work absenteeism, premature death and missed school, and the subsequent cognitive development and lifetime productivity impact) are typically included in a limited form (e.g., absenteeism and using the friction cost approach) in most countries. Societal health gains from disease eradication could only be considered (at least in principle) in Germany.

Few of the Dimension III concepts are included in current vaccine HTA with large variations across countries. Germany has (in principle) the broadest value perspective, including the most value concepts; however it is not always applied extensively. Several countries consider concepts of this dimension such as societal preference fulfilment and social equity/ethics, but only in ad hoc deliberative processes. Macroeconomic gains (e.g., affecting the national economy, gross domestic product [GDP], tourism, investment influx, financial sustainability) have been considered in some circumstances (e.g., COVID-19 impact in the UK [34]), and for specific vaccines in the UK (e.g., congenital rubella).

3.2. Prioritisation of VoV concepts for HTA inclusion

The eight criteria used to score each concept (i.e., five criteria relating to decision-making and three to feasibility of measurement; see Fig. 2) were given a weighting by each expert to reflect their relative importance (Fig. 4). For example, in most countries, criteria 1 (how important a value concept was in determining VoV) was considered more important than criteria 8 (if it is possible to capture the concept in CEA).

In addition to the experts' absolute ranking of concepts by importance, each concept was scored against each of the eight weighted criteria to obtain a relative ranking of concepts. Fig. 5 presents the aggregated results of the ranking and scoring exercise across all countries.

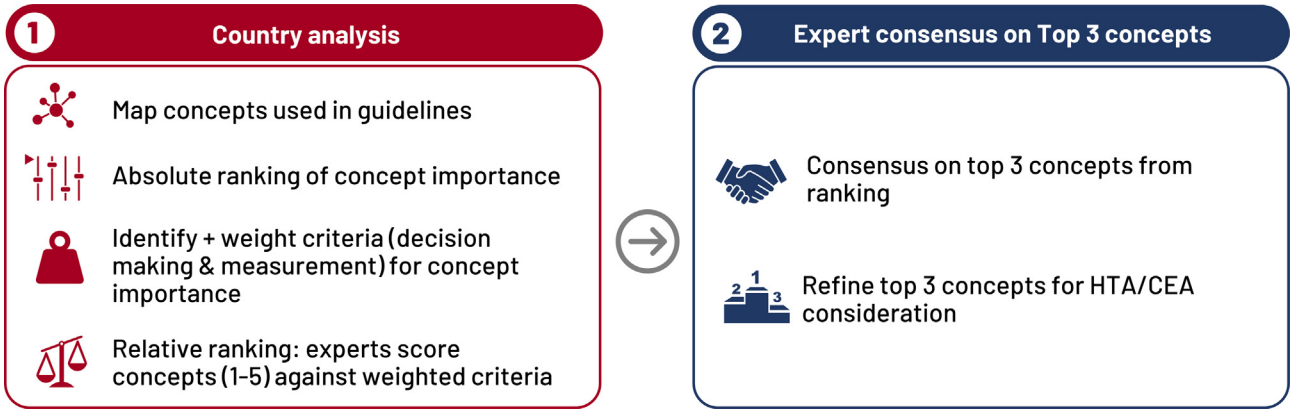

Fig. 1. Overview of study phases with key objectives. CEA: cost-effectiveness analysis; **HTA:** health technology assessment.

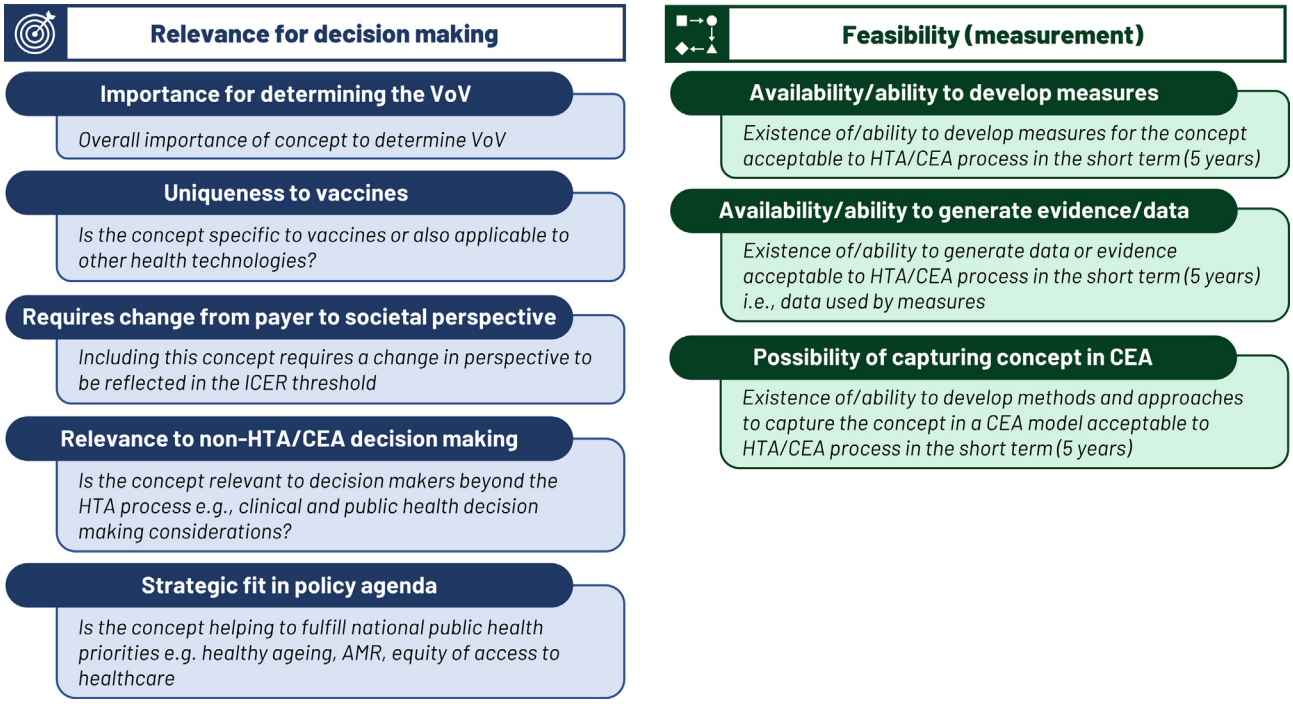

Fig. 2. Criteria to prioritise VoV concepts for the ranking exercise. AMR: antimicrobial resistance; **CEA:** cost-effectiveness analysis; **HE:** health economics; **HTA:** health technology assessment; **ICER:** incremental cost-effectiveness ratio.

Conventional payer and societal perspective HTA concepts (i.e., health gains to vaccinated individuals, direct medical cost savings, societal health gains beyond vaccinated individuals and productivity gains in vaccinated individuals) were frequently ranked in the top-five in absolute and relative rankings. When concepts were scored according to 'decision-making relevance' and 'measurement feasibility' criteria, macroeconomic gains emerged as an additional novel top-five concept followed by social equity and ethics (ranked sixth). These concepts scored highly as important concepts for determining the VoV (criterion 1 'importance for determining VoV') – which was the driving criterion for overall ranking. Therefore, based on the ranking/scoring exercise plus the country analysis highlighting concepts currently lacking in HTA/CEA, the top three key concepts selected for prioritisation in future HTA/CEA were 'macroeconomic gains', 'social ethics and equity', and 'health systems strengthening, resilience and security'. The choice was made a priori to select only three concepts for pragmatic reasons, to allow sufficient in-depth development of these concepts and how to implement them within reasonable study timelines. There was consensus among the experts that these concepts should be prioritised when expanding the VoV captured in HTA/CEA of non-pandemic vaccines in the near to midterm future. Below, we briefly review the definitions of the three value concepts selected.

The VoV framework developed in this study currently defines the concept of macroeconomic gains by the following value elements: 1) changes in the national economy or individual sectors of the economy; 2) impact on GDP or production by economic sector beyond productivity gains attributable to individuals or households (e.g., profit gains of companies or gains in tax revenues); 3) reduction in tourism loss; 4) poor health is associated with lower foreign direct investment inflows; and 5) improved financial sustainability as a result of effects such as synergies with other health care programmes (e.g., delivery platforms), stimulation of private demand, and mechanisms to enhance group purchasing power.

The concept of social equity and ethics is currently defined as: 1) more equal distribution of health outcomes; 2) avoidance of household medical impoverishment due to treatment costs, which can widen health and financial equity gaps within and between communities; 3) vaccines have additional value as a method to promote health equity across sub-populations by addressing inequality in access to healthcare services, because vaccine benefits often accrue disproportionately to poorer communities and some racial and ethnic minorities; 4) the empowerment of women; and 5) ethical values.

The concept of health systems strengthening, resilience and security is currently defined as: 1) health system efficiency gains: fewer infectious disease cases means healthcare resources (e.g., medical supplies and professionals' time) can be reallocated more efficiently (e.g., to other patients or to research and development efforts), easing the strain on hospital budgets and benefiting other patient groups with unmet needs; 2) implementation of immunisation programmes provides an incentive for governments to improve their health systems in order to efficiently deliver preventive interventions; and 3) reduction in health system disruption caused by unpredictable outbreaks or epidemics.

As these three concepts can be defined in a broad way with many different value elements, consensus will be needed on the final definitions, for a consistent HTA approach. As such, the elements to be included in the concept definition should meet certain prerequisites: relevance for decision-making and measurement, possibility of inclusion in HTA/CEA in the near to midterm, and adaptability to the country setting.

Besides these top-three value concepts currently missing from HTA/CEA assessment in the context of near to midterm focus, this study has shown a range of important concepts in Dimension III that should be captured in the long-term (Table S1). This would require more research into methods for quantification, and evidence generation to reduce uncertainty regarding their impact.

4. Discussion

The guideline review for vaccination value concepts showed there is often a focus on payer perspective benefits with limited con-

Fig. 3. Inclusion of VoV concepts in HTA/CEA across countries. **a**: e.g., herd immunity; **b**: e.g., disease eradication; **c**: e.g., decrease in AMR; **ACIP**: Advisory Committee on Immunization Practices; **AMR**: antimicrobial resistance; **CEA**: cost-effectiveness analysis; **HTA**: health technology assessment; **VoV**: value of vaccination.

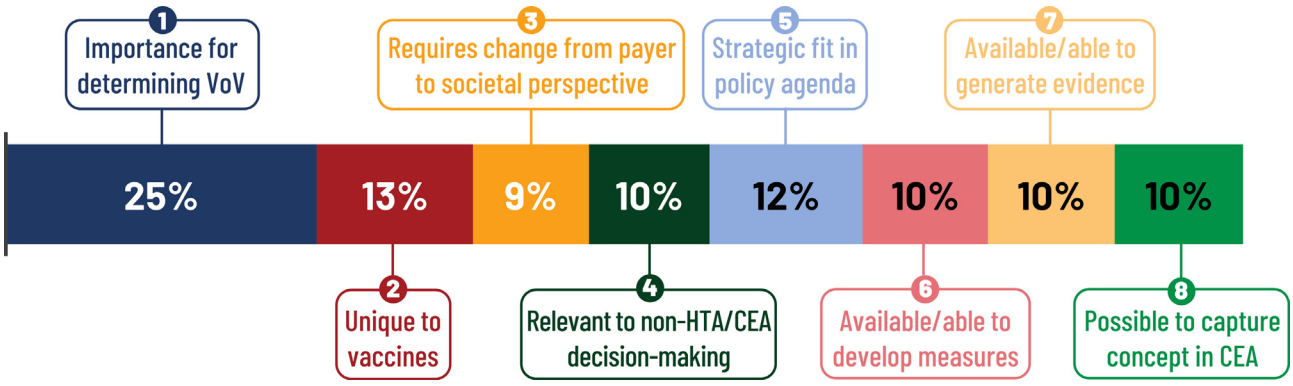

Fig. 4. Relative importance of eight criteria to assess concepts – average from experts across countries. CEA: cost-effectiveness analysis; **HTA:** health technology assessment; **VoV:** value of vaccination **Note**: the numbers presented are rounded up, the total adds up to 100%.

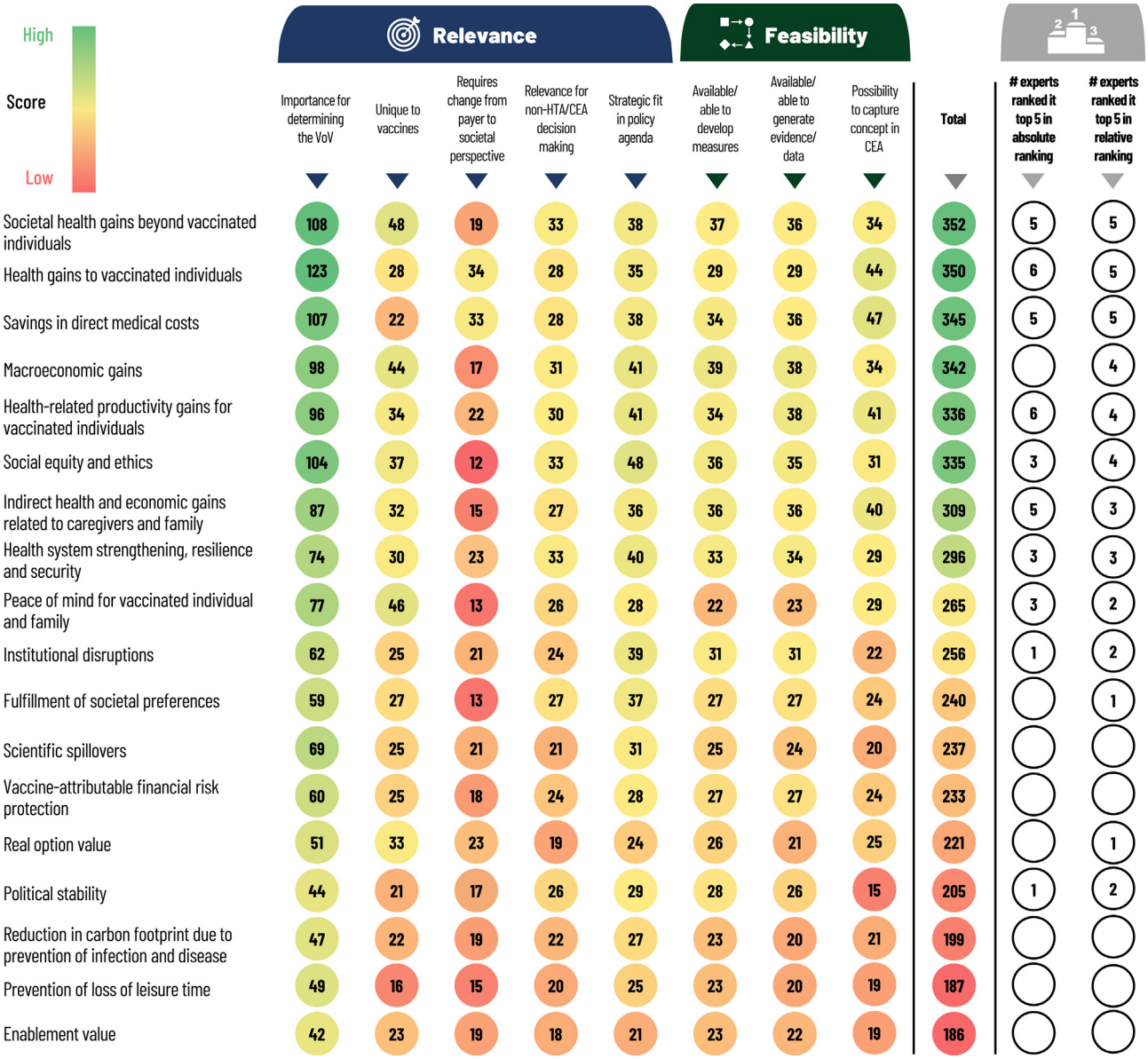

Fig. 5. Concepts ranked based on 'relevance to decision-making' and 'feasibility of measurement' criteria scores, and concepts most frequently in top-five absolute and relative rankings. CEA: cost-effectiveness analysis; **HTA:** health technology assessment; **VoV:** value of vaccination **Absolute ranking:** concepts ranked in order of importance; **Relative ranking:** concepts ranked after scoring each concept against the eight weighted criteria.

sideration of societal benefits, except (in principle) in Germany, the Netherlands and the US. While decision-makers in France also consider broader societal benefits, these are not included in CEA, which is typically used as a tool for price negotiations. There were also differences noted between the guidelines and current practice, with many societal value elements not included in actual assessments or inconsistently included and without transparency in deliberative processes. For example, in the US and France, societal health gains beyond vaccinated individuals (e.g., health gains to wider society from reductions in transmission and herd immunity or outbreak control/preparedness) are not generally considered. Although the focus was on relatively similar high-income countries with established HTA/CEA processes, these differences may contribute to differences in policy decisions within and across countries. Within Europe for example, rotavirus vaccine is recommended in the UK, Germany and Italy but not in France, it is only recommended for specific groups in the Netherlands and Spain, and it is recommended but not funded by the national health system in Belgium [35,36]. In Spain, regional variations in decision-making processes are often driven by monetary considerations e.g., meningococcal B vaccination is recommended in Castilla y León [37] but not in other regions such as Andalucía [38]. Differences in vaccination policies and differences in the consideration of the value of vaccines can potentially result in variable access to vaccination and health inequities across and within high-income countries.

The extensive impact of the COVID-19 pandemic on society in countries around the world has helped to raise awareness about how vaccination can have a positive effect on many sectors, beyond the health sector and vaccinated individuals [4]. The VoV framework developed includes 18 unique areas where vaccination can provide benefits to individuals and society [18], but the country analysis showed that most of these value concepts are not integrated in current HTA/CEA. Stawasz et al. (2020) [39] assessed how different value considerations in HTA in France, Germany, the US and the UK resulted in different meningococcal B (MenB) vaccination policies against an uncommon but severe disease. The UK was the only country to consider the broad value of MenB vaccination (including novel HTA elements such as impact beyond the patient), and found it to be cost-effective, resulting in its inclusion in the NIP [39].

The scope of vaccine benefits included in HTA/CEA needs to be expanded. Many of the broader value elements identified require further evidence generation and methodological research. While some concepts may already be included using different methodologies such as cost-benefit analysis e.g., in the economic evaluation of meningococcal B vaccination using a lifecycle model [40], these methods are not currently used by HTA bodies or NITAGs in the health economic assessment of vaccination programmes. Therefore, there needs to be a change within the existing HTA process that is incremental e.g., through gradual expansion of concepts within current analysis frameworks and a shift to standard inclusion of societal benefits.

In [18], we identified almost 30 published frameworks put forward to highlight the under-recognised but broad and unique value that vaccination might bring to public health. Brassel et al. [41] for example, assessed which value concepts would be considered and which would be disregarded for a range of specific vaccines in the pipeline. They concluded that the current narrow HTA framework systematically undervalues the benefits of vaccines by not considering their impact on antimicrobial resistance, enablement value or productivity [41].

The comprehensive framework proposed in this study is novel in that it supports potential near-future expansion of HTA, by classifying value concepts along a spectrum from conventionally-used payer to societal concepts, and to novel societal concepts in HTA. Using this pragmatic focus and approach, value components were ranked according to what is important to decision-makers and, at the same time, what can be implemented in existing analysis frameworks e.g., in economic models. The three priority concepts identified need further development (i.e., clear definitions specifying which value elements are included and how to measure them as well as identification of methodologies to be included in or complement CEA), to be able to inform policy decision-making and for inclusion in HTA in the near future. The focus of our study was on non-pandemic vaccines. However, when considering the VoV during a pandemic or emergency setting, the relative importance and magnitude of impact of concepts could differ from our findings. In emergency situations, the criterion of vaccination meeting cost-effectiveness thresholds may even be disregarded at first. During the COVID-19 pandemic, for example, the impact of vaccination on minimising 'institutional disruptions' was a critical value benefit, while during the 2014 Ebola epidemic in West Africa, the impact of vaccination on concepts of 'political stability' and 'macroeconomic gains' played an important role [42].

Lakdawalla et al. [43] developed another framework from a health economics perspective, not specific to vaccines, which identified eight potential novel value elements not used currently in HTA but relevant from a societal perspective. Some are particularly relevant to vaccination (e.g., equity, value of hope, fear of contagion, reduction in uncertainty). While their paper did not prioritise any elements for practical implementation, the authors did discuss how feasible and meaningful quantifying each element would be, the potential impact of including them, and they also suggested regulatory authorities are ready to expand the scope in HTA and include broader value considerations [43].

The other value concepts, currently novel to HTA, are also potentially relevant, but require more active research and development within and beyond the health sector, for potential long-term inclusion in HTA. A few of these novel concepts may be assessed within CEA, but the majority will require a broader analysis approach, such as cost–benefit analysis [44] or multi-criteria decision analysis [45], while others may only be defined qualitatively. Evidence, from prospective and/or retrospective studies, will need to be generated soon to support the future use of these value concepts in HTA.

This analysis was limited by the focus on developed HTA countries applying CEA to allow cross-country comparisons and transferability of new methods, and by the inclusion of mostly one expert per country. Despite this, we attempted to use a robust and structured approach to rank and prioritise the most important value concepts for near-term HTA inclusion. The ranking and prioritisation processes, however, can also be useful to other countries, although the outcomes could differ according to specific national priorities, the structure of the healthcare system and availability of HTA processes and societal views. For instance, in other countries with universal health coverage and a well-developed HTA process using CEA to inform policy decisions (e.g., Canada, Italy), the ranking/prioritisation process can be applied using similar or the same criteria. For low and middle income countries, however, new criteria may be required to rank the value concepts not yet considered, for example, financial risk protection could play a more significant role where no universal health coverage exists. The expert panel included decision-makers and health economists, to ensure a range of viewpoints and experience. While there were differences in the experts' opinions (e.g., different weights assigned to criteria for determining the value of each concept), the discussions at the Advisory Board meeting aimed to reach a consensus, so that the findings can improve consistency in policy decisions across countries in the future. The process used, including prioritisation criteria and their discussion, was intended to clearly and transparently show how priority concepts can be selected, to ultimately support national decision makers involved

in these discussions. Only the top three concepts were chosen for in-depth study due to time and organisational constraints. The other concepts are also important, sometimes only marginally less important than these top three e.g., 'peace of mind', as shown in the ranking. The concepts included were taken from studies across paediatric and adult populations.

The final publication in this three-part series set will focus on exploring methods for the adoption of the three priority concepts. Expanding the VoV concepts included in HTA of vaccines is warranted to increase decision making transparency, by moving away from deliberative processes towards quantitative assessment. Although this might lead to increased input parameter uncertainty, it will, nonetheless, reduce the structural and overall uncertainty around the impact and value of vaccination programmes under assessment.

5. Conclusions

In conclusion, we have highlighted some of the gaps in current vaccine economic assessments which lead to inconsistent policy decisions across countries. We have also used a rigorous approach to identify three key missing value concepts that should be included in HTA/CEA of vaccines in the near future: macroeconomic gains, social ethics and equity, and health systems strengthening, resilience and security. The outcomes of this study aim to help identify priorities for methods development and, ultimately, to strengthen the evidence available to support decisions about vaccines that better reflect their value to society. The study was conducted with no specific vaccine in mind. The objective was to contribute to the extensive work on the VoV, with the hope of generating debate and fostering work from professional organisations and academia, to initiate a systematic discussion on the VoV internationally.

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Author contributions

All authors are members of the Advisory Board and provided substantial input, contributing to writing and reviewing of this publication. Maarten Postma and Eliana Biundo led this publication development. All authors gave their final approval and are accountable for all aspects of the work.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Maarten Postma received grants and/or consulting fees and/or honoraria from Foundation for Progress and Health (Andalusian Regional Government), Department of Health, Regional Government of Extremadura, Ministry of Science and Innovation of Spain, Spanish Confederation of Housewives, Consumers and Users Organisations (CEACCU), Royal Academy of Medicine and Surgery of Eastern Andalusia, University of Granada, Alicante, Seville, Seville, Basque Country and Pompeu Fabra and regional government outside of this work.

Eliana Biundo, Ekkehard Beck, Mark Doherty and Shazia Sheikh are employed by and hold shares in the GSK group of companies.

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Terry Nolan was a member and co-chair of the Advisory Board for this study, established by the GSK group of companies, and was paid an honorarium for his input. He received consulting fees and/or honoraria from AstraZeneca, Merck, Seqirus, Sanofi Pasteur and the GSK group of companies, as well as personal payment for participation in other advisory boards, not related to this study, from Clover, Zeria and the Serum Institute of India. He is an expert in the Victorian State Government advisory group on COVID vaccine roll-out, outside of this submitted work. His institution received grants from the GSK group of companies, Sanofi Pasteur, Janssen, Seqirus and the Serum Institute of India outside of this work.

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Appendix A. Supplementary data

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