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Abstract

Health indexes have been used to evaluate population health in its multiple dimensions, providing valuable information to drive health related policies and the planning of health services. Nevertheless, health indexes reported in the literature have often lacked theoretical foundations and incurred in drawbacks. Aiming to contribute to this literature, this study proposes (and applies) a framework that combines concepts from multicriteria value measurement with participatory methods to build a value-based population health index. From the technical side, the MACBETH approach was used to construct the population health index within a hierarchical multicriteria model structure, with the model having two main areas of concern – health determinants and outcomes – that are specified by a set of evaluation criteria in which several dimensions of the health of a population are appraised. From the social side, the application of MACBETH was supported by a combination of participatory methods including a modified Delphi process with a large group of health stakeholders and experts, and decision conferences with a strategic group. The proposed framework was applied to build an index to evaluate population health at the municipality level in Portugal over the past twenty years (within the scope of the GeoHealthS research project). The index generates a wide set of outputs within a ''tableau-de-bord'' structure which will integrate a Geographic Information System and will be the starting point for policy makers and planners analysing variations in population health and geographical health inequalities in the Portuguese territory and to evaluate the impact of health and health equity oriented policies.

1. Introduction

A common goal among the health systems of OECD countries is to improve the health of individuals and populations in an equitable, efficient and effective way [1]. Therefore, assessing the health of populations and tackling geographical health inequalities are very important challenges for governments and health decision-makers [2, 3].

Population health comprises multiple aspects, including the burden of disease, quality of health care, individual behaviour, education and environment [4, 5, 6, 7]. Hence, appraising population health and accessing patterns of health and disease in the community requires the development of formal assessment tools, such as health indexes, that consider both health determinants and outcomes [8]. The main advantage of these indexes is their capability of considering multiple aspects and simultaneously delivering an aggregate score that permits a global view of population health [9], being regarded as an efficient information tool [1] that "facilitates the targeting of health resources based on health needs from a multidimensional perspective" ([10], p.246).

Nevertheless, there are accuracy and reliability issues associated with health indexes [10], as most of the times they are built with resort to *ad hoc* processes [9] and used as black boxes [1], potentially leading to distorted results and to misleading conclusions. Above all, the construction of a health index is not a straightforward process since it involves assumptions that need to be properly assessed to avoid a tool with dubious analytic rigor [11]. Smith emphasized that the process of constructing these indexes is "in its infancy, and many of attempts to date have been seriously inadequate from a technical perspective" ([12], p.309). Hence, it is recognised a need to develop comprehensive evaluation tools, based on methodologically sound procedures, which can adequately evaluate population health in its multiple dimensions, providing valuable information for building health oriented and equity based policies.

This paper proposes a framework to build a (multidimensional) value-based population health index with the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) approach, combining concepts and methods from multicriteria value measurement and participatory methods. The model was designed (and built) within the scope of the GeoHealthS R&D project to develop a population health index to evaluate population health in Portuguese municipalities over the past 20 years (in the years of 1991, 2001 and 2011). The index is to be used within a web-based Geographical Information System (GIS), to be made available to health decision-makers and to the general public, so that health patterns could be analysed and explored. In this paper we focus on the design of methods to build this population health index, rather than on the results from its application.

The paper is structured as follows: section 2 briefly reviews approaches that seek to evaluate population health on multiples dimensions; section 3 presents the proposed framework for building the value-based population health index; section 4 describes how the multicriteria approach was developed to build a health index to evaluate population health at the municipality level in Portugal over the past twenty years. Finally, section 5 discusses issues and lessons learned from the process of developing and implementing the health index.

2. Literature review

Population health has been described as involving the measurement of health outcomes and their distribution within a group of individuals, the patterns of determinants that influence such outcomes, as well as the policies that influence the optimal balance of determinants [13, 14]. Monitoring and evaluating population health is crucial to understand the major health challenges of each community or geographic area, providing appropriate and timely information to guide the elaboration of future guidelines and interventions, and consequently, help policy-makers to allocate the available resources according to their objectives and goals [15].

Individual health indicators, as mortality rates, life expectancy and years of life lost, have been traditionally used by governments to make decisions regarding resource allocation in health care [8, 10]. Nonetheless, individually-based health indicators are unidimensional [10] and do not capture all the relevant aspects that influence the health of populations. In response to this, there has been a growing trend in the use of multidimensional tools that aggregate several indicators in an overall score permitting: a) a more rounded, comprehensive and accountable assessment of system performance than single indicators [12]; b) a clearer overview of population health and health care performance which simplifies the process of comparing different geographic areas [9], while considering multiple health aspects [16]; c) the definition of targets in each indicator used in the index, enabling benchmark analyses [8]; d) the delivery of information for analysing overall health performance of the population of a geographical area, through the use of a type of traffic light system [17]; and e) the incorporation of geographical information [18], which can help policy-makers and health decision-makers to explore "trends and relationships over space and time in order to monitor the influence of government policies such as those aimed at reducing health inequalities" [19].

Nevertheless, literature points out for problems in the construction of these indexes [8, 9, 10, 20], partly due to difficulties in the choice of indicators to be included in the index and in the use of methods to aggregate indicators in an overall measure; this aggregation procedure is usually compensatory, which can mask some important problems regarding population health (for instance, a good score may mask serious shortcomings in some indicators, being difficult to determine the precise source of failings and, therefore, remedial actions are not implemented). Kaltenthaler et al. [10] have further emphasized that health indexes must undergo extensive testing to ensure their reliability and validity.

In a review of the literature, we have searched in ISI Web of Knowledge, Pubmed, Science Direct and Google Scholar databases for studies using "composite measure", "composite index", "composite indicator", "deprivation index", "area index" or "health index", and found that that these tools have been built resorting to the following approaches: data envelopment analysis (DEA) [21, 22], statistical methods [23, 24, 25, 26, 27, 28, 29, 30] and multi-criteria decision analysis (MCDA) [31, 32, 33, 34, 35, 36]. Many approaches rely on *ad-hoc* processes that lack sound theoretical foundations [4, 6, 16, 37, 38]. Although DEA and statistical methods allow for computing global measures, they do not allow for a transparent evaluation of population health, nor the definition of meaningful references for each indicator in use (thus precluding benchmark analyses). MCDA approaches have already shown: to be a useful method for building health indexes [31, 32, 33, 34, 35, 36], allowing for spatial analysis of population health (see for example [39, 40]); to have sound theoretical foundations [41, 42, 43]; and to produce transparent models that consider both evidence and all the viewpoints of health stakeholders and experts. However, studies using MCDA techniques have often incurred in well-known mistakes reported in the decision analysis literature, which precludes the use of several of the proposed indexes. Such errors include: i) not distinguishing between the notion of performance and the notion of value (e.g. [31, 33, 36]); ii) weighting on the basis of the notion of intrinsic importance leading to “the most common critical mistake” (e.g. [36]) and iii) applying the MCDA approach Analytical Hierarchy Process (e.g. [32, 34, 35]) that presents reported methodological problems (for details see [42, 44]).

Overall, the process of building tools to measure population health “is in its infancy” ([12], p. 309) and several methodological problems still need to be addressed. In fact, it is necessary to build health indexes that:

a) incorporate all the relevant aspects that capture and/or influence the health of a population (there being no aspects neglected due to lack of data availability);
b) do not confuse performance indicators with evaluation criteria;
c) reflect not only scientific evidence but also the concerns and strategic objectives of health stakeholders, through the use of appropriate participatory methods;
d) deal with possible synergies and interactions between performance indicators;
e) assign relative weights to the criteria that adequately reflect value trade-off judgments between criteria;
f) are validated and do not mask critical problems regarding population health;
g) generate a wide range of outputs, within a management “tableau-de-bord” structure (see [45] and [46]) that can be used to populate a GIS (for instance, including the performance profile of each geographic area, as well as aggregated and disaggregated values of population health in multiple dimensions).

MCDA allows for building a multicriteria model to support the measurement of a health index in a transparent, comprehensive and systematic manner, as well as provides sound methods [41, 42, 43] and which fulfils the requirements and conditions outlined before. Hence, this study proposes a novel framework to support the construction of value-based population health index, to be used for evaluating population health status at municipal level on multiple dimensions based on concepts and methods of multiple criteria value measurement [41, 42, 43].

3. Multicriteria modelling for a value-based population health index

3.1 Methodological framework

A socio-technical process [47] was designed for building a value-based population health index: it integrates the technical elements of a multicriteria value model (with sound theoretical foundations [41, 42, 43]) and the social elements of participatory methods, involving the use of a modified Delphi process with a large and multidisciplinary group of nineteen health stakeholders and experts – the SK-Group – and decision conferencing with a smaller strategic group with five members – the ST-Group (this is a sub-group of the SK-Group).

The use of participatory processes to build the multicriteria value model allows for combining scientific evidence with the opinions of different experts and stakeholders (e.g. epidemiologists, geographers, economists and policy-makers) with different health backgrounds to build the multicriteria value model. Following the insights from Buescu and Chen [48], the aggregation of multiple sources of information maximizes the amount of information available to build the evaluation model, reduces the potential impact of stakeholders and experts that rely on inaccurate and unreliable information, as well as increases the credibility and validity of the model by making it more inclusive and representative.

The constitution of two groups of decision-makers (SK-Group and ST-Group) was driven by the need of having, on the one hand, a multidisciplinary and large group - SK-Group - with different experts and stakeholders that have different perspectives and skills, belong to different regions of Portugal and can provide valuable insights to the construction of the model; and, on the other hand, a strategic group (ST-Group) that has a holistic view of the index-building process, is big enough to be representative but simultaneously small enough not to preclude the effectiveness of the process [49], and that is available to participate often in face to face meetings.

Both groups were designed to participate in distinct formats in different parts of the index building process. For instance, the SK-Group was involved in a modified Delphi process [50], with the use of this participatory method being motivated by two reasons: firstly this is an anonymous process implying that panel members can shift position without losing face if they see convincing reasons for doing so; and secondly, it does not require physical presence. The ST-Group, within a decision conferencing process, was engaged in building the multicriteria value model that underlies the population health index. This participatory process allows the group to develop a shared understanding of the issues, generate a sense of common purpose, gain commitment in the way forward and confidence in the results provided by the model [47] to be used for evaluating population health. These participatory formats were further enhanced with complementary workshops, as described below.

Methodologically, the index-building process can be viewed as a package of interconnected activities to be developed with both groups, as detailed in Fig. 1 and briefly described in this section and discussed in detail in the next sections.

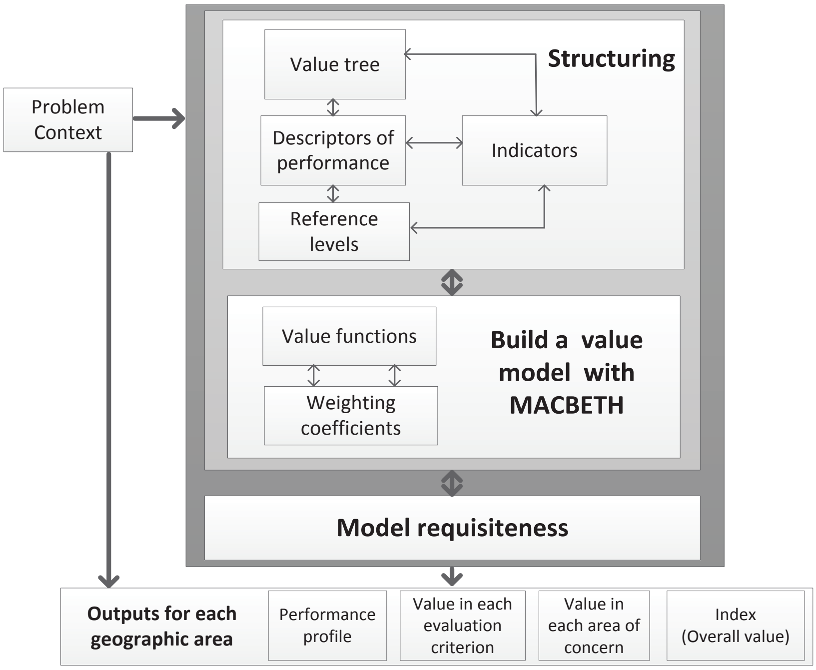


Fig. 1. Activities developed for building the multicriteria evaluation model, and respective outputs.

The methodological and contextual issues related to population health were initially discussed with the SK-Group, there being an agreement regarding the scope of population health and subsequently on the adoption of a multicriteria modelling approach. During this discussion, and given the index is to be used to evaluate population health in different years, it was established that the model would reflect scientific evidence and the current views of experts and stakeholders regarding population health, implying the construction of a model that is to be used for *ex-post* evaluation of population health in previous years.

In structuring the model, the SK-Group selected a group of 64 indicators that considered important to evaluate population health at the community level; this selection was based on the group knowledge and on scientific evidence regarding the link between each indicator and population health. Based on the discussion of each indicator, overlaps and redundancy between indicators were detected and eliminated; and a set of dimensions important for the evaluation of population health were defined. To overcome problems of interdependency and synergies between dimensions, a series of systematic tests were performed with the support of a tool named Multicriteria Cognitive Map, by using the concepts and procedures described in [51]. These procedures allowed for defining a set of (difference independent [52]) evaluation criteria in which the status of population health should be appraised – we leave outside the scope of this article a description of the technical processes involved in this step. While in most cases evaluation criteria entailed one dimension (e.g. Obesity), in a few cases an evaluation criterion comprised several interrelated dimensions – for example, the criterion "hospital responsiveness" encompasses the "doctors in hospital care" and "hospital beds" dimensions, as one cannot evaluate how important is improving the number of beds if one does not know if there are sufficient doctors to treat more inpatients.

Finally, the set of evaluation criteria were grouped in different areas of concern, leading to the construction of an initial tree (we name this tree as a value tree as it embodies all the dimensions contributing for population health). The initial proposal for the value tree was presented to the SK-Group in a workshop. After discussion within the SK-Group and several iterative modifications with the ST-Group, a new proposal for the value tree was achieved and presented in a new workshop, in which the SK-Group commonly accepted the proposed tree.

In this process of structuring the value tree, a descriptor of performance (i.e. an ordered set of plausible performance levels) [53] that makes each criterion operational for evaluating population health and allows tracing the performance profile of each municipality, was assigned to each evaluation criteria. In the aforementioned cases in which the evaluation criterion comprised only one dimension, the descriptor assigned was a quantitative indicator; in the few cases in which evaluation criteria encompassed several interrelated dimensions, the assigned descriptor comprised a cluster of several interrelated quantitative indicators.

Building an evaluation model requires the definition of two reference levels for each descriptor with substantive meanings [53], as such references are required for benchmark analysis (for instance allowing to investigate the distance in performance of each municipality to the reference values) and later for building weighting coefficients (required for aggregating value in different criteria). Several studies (see, for example, [45, 53, 54]) have shown the relevance of using as references: a "neutral" level that traduces the level of performance for a given criterion that is regarded as acceptable (neither attractive nor unattractive), and a "good" level that makes explicit what is a good performance in each criterion expressing a clear commitment to achieve a specified result in a defined time period. Given the need for evaluating population health in different time periods, these references needed to be defined generally and in a meaningful way to be applied for the years in which population health is to be evaluated (for 2011, 2001 and 1991 in our application to the Portuguese context). In this way, two statistical measures were used as proxies – "base_year" and "top10%_year" – for the "neutral" and "good" levels, respectively. The "base_year" level was set as an average of the performance of the municipalities in the year and a "top10%_year" level was set as the average of the performance of the 10% best municipalities in the year. When applied to the set of years for evaluation, these references allow for identifying poor and good performance in all the evaluation criteria relevant for evaluating population health.

Once evaluation criteria were defined and descriptors of performance were selected, several activities were required to transform performance into partial and global population health value scores. The first activity was to build value functions, enabling performance to be transformed into value in each evaluation criterion (this process will be detailed in sections 3.3.1 and 3.3.2). In order to evaluate population health at the level of each area of concern and in overall terms, the value scores on the criteria and across areas (that capture partial value) were to be aggregated, requiring a conversion of partial value into a value scale of population health. With this purpose, criteria and area weights were determined using a hierarchical additive value procedure. These weighting coefficients are key to determine the value profile of each municipality within and across areas, and the aggregated (population health) value for each municipality (see Fig. 2), and will be explained in detail in section 3.3.3.

To build these value functions and weighting coefficients, the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) [55, 56] approach was chosen as, contrary to other numerical techniques (such as direct rating [57]), it only requires qualitative judgements about differences of attractiveness to quantify the relative value of each municipality in each criterion, area of concern and in overall terms (see the mathematical foundations of MACBETH in [58]). MACBETH has been successfully applied in several contexts (see, for example [45, 53, 54, 55, 56, 57, 59]), and its use is being supported by the recently created hierarchical version of M-MACBETH [60] and by the WISED [61] decision support systems (DSS).

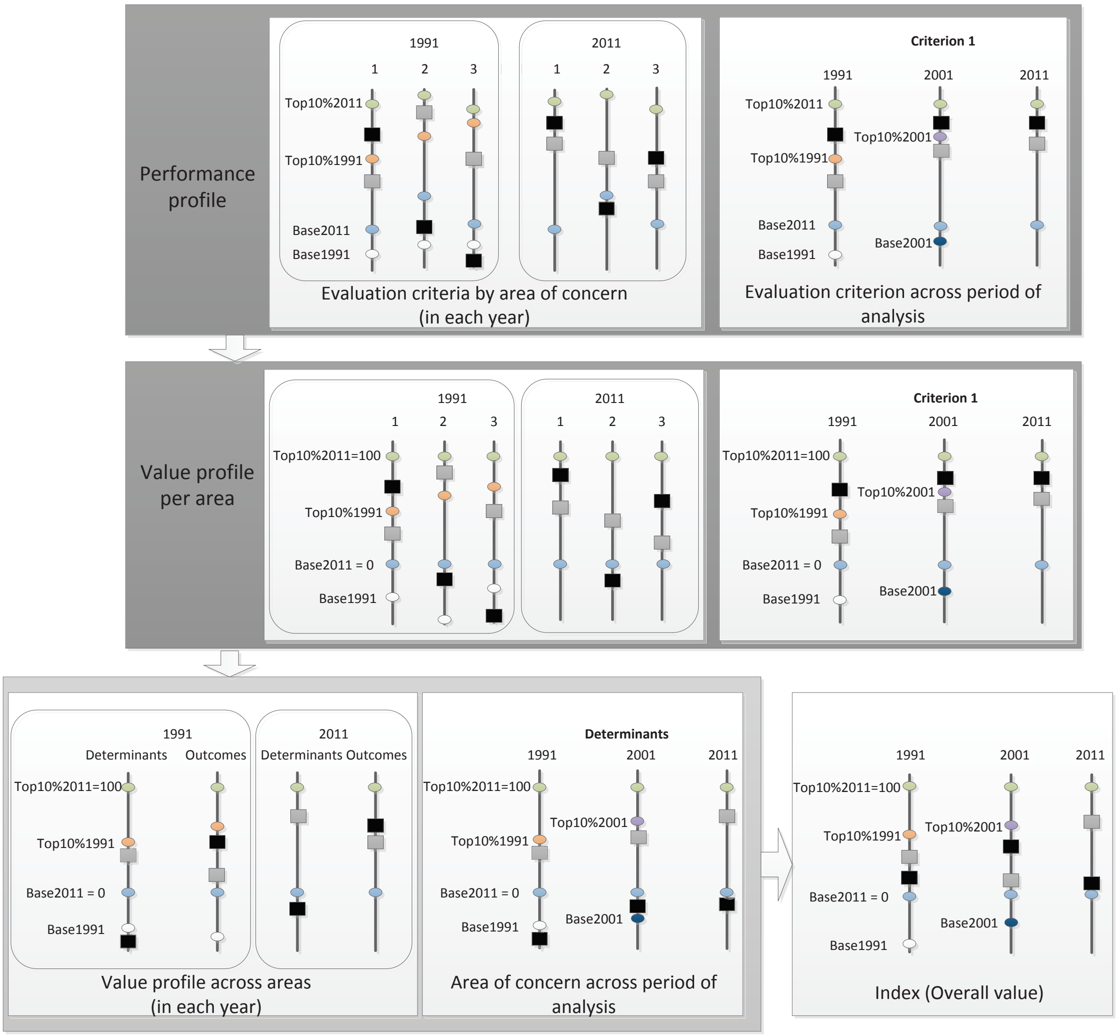


Fig. 2. Representative (generic) visualization of model outputs.

Despite the reliability of the model to evaluate population health is partly ensured by the use of sound methods (see [42] and [43]), validity tests are required. For this purpose, several procedures were designed. First, the model to evaluate population health was developed in a recursive way, as captured by the loop arrows in Fig. 1. This means that whenever necessary, previous work done in model development was revised (for instance, restructuring the selection of evaluation criterion and changing weights). Then, extensive analyses of model results (using aggregated and non-aggregated scores) of a group of representative municipalities were carried out by the ST-Group. The model was developed until it was considered ''requisite'' [62], i.e., when its form and content were deemed as appropriate for evaluating population health at a community level in practice [47].

3.2 Multicriteria model to evaluate population health

The mathematical elements of the multicriteria value model built with MACBETH are as follows. Let i_h = 1,…,n designate the evaluation criterion *i* (e.g. "Obesity") of the area of concern *h* (e.g. "Life Style"), X_{i_h} the descriptor of performance of criterion i_h (e.g. "Percentage of adults (age 20 years and over) who are obese or are overweighed") and v_{i_h} (.) the respective value function. Let $x_{i_h}^m$ be the performance of a municipality *m* on criterion i_h and $v_{i_h}^m(x_{i_h}^m)$ the respective value score; let $(x_{1_h}^m, \dots, x_{n_h}^m)$ and $(v_{1_h}^m(x_{1_h}^m), \dots, v_{n_h}^m(x_{n_h}^m))$ be the performance and value profile of municipality *m*, respectively. Then, the evaluation of population health of a municipality *m* in the area of concern *h* is given by the simple additive model (1):

$$v_h^m\left(x_{1_h}, \dots, x_{n_h}\right) = \sum_{i_h=1}^{n_h} k_{i_h} v_{i_h}^m(x_{i_h}^m) \qquad with \begin{cases} v_{i_h}\left(top10\%\_2011_{i_h}\right) = 100 \\ v_{i_h}\left(base\_2011_{i_h}\right) = 0 \end{cases} \qquad (1)$$

where $top10\%\_2011_{i_h}$ and $base\_2011_{i_h}$ are, respectively, the ''top10%'' and the ''base'' reference levels of performance on criterion i_h in the year of 2011; and k_{i_h} are the weights assigned to criteria, when those references are considered, and such that $\sum_{i_h=1}^{n_h} k_{i_h} = 1$ and $k_{i_h} > 0$. By applying model (1) bottom-up successively, it is possible to compute the (population health) value in each area of concern, in the different levels of the hierarchy of the value tree, and in overall terms.

The proposed additive model makes use of interval scales, implying that the zero assigned to the "base level" of 2011 is a matter of convenience [42]. Consequently, only the relative magnitudes of differences between the municipalitys' scores have a meaning, and the attribution of zero and 100 to the references is arbitrary. Therefore, although the model is built with two references, the model outputs may be rescaled through linear transformation. This is important as the scale used to build the model may be deemed as inadequate for communicating results – for example, by fixing the zero on "base level" of 2011, it is expected that several municipalities in 1991 and 2001 present negative scores (by having performances below the "base level" of 2011 in several criteria) - but a different scale of value can be used to communicate results.

3.3 Design of participatory methods

Participatory methods comprised the use of decision conferencing with the ST-Group and workshops and a modified Delhi process with the SK-Group to carry out the evaluation activities of Fig.1:

- the ST-Group, in a series of decision conferencing workshops, was involved in structuring the set of evaluation criteria and in building the value model. Along the decision conferencing process [48], developed in several structured meetings, neutral facilitators guided the ST-Group to build an evaluation model on-the-spot, capturing the knowledge and concerns of the group [48] and encouraging the group to represent its collective judgements in a logically consistent and easily communicated fashion [63]; individual differences of opinion were allowed. A face-to-face environment promoted a successful collaboration between members of the ST-Group. This decision conferencing process was supported by the MACBETH approach. Decision conferencing workshops were combined with intensive homework by the members of the ST-Group. Intercalated with the decision conferencing meetings, a few workshops with the SK-Group also took place, so that all participants could have a better understanding and comment the methods in use and could improve their understanding on the components of the model to evaluate population health.

- the SK-Group, resorting to a modified Delphi process (the design of this process is described below), provided valuable information to help the ST-Group in the construction of the value functions for each evaluation criteria.

Fig. 3 summarises the timetable of the process including the decision conferences workshops, the meetings with the SK-Group and the modified Delphi process. Note that this process is not concluded, and a meeting for validating the model outputs with the SK-Group is still scheduled for September 2014.

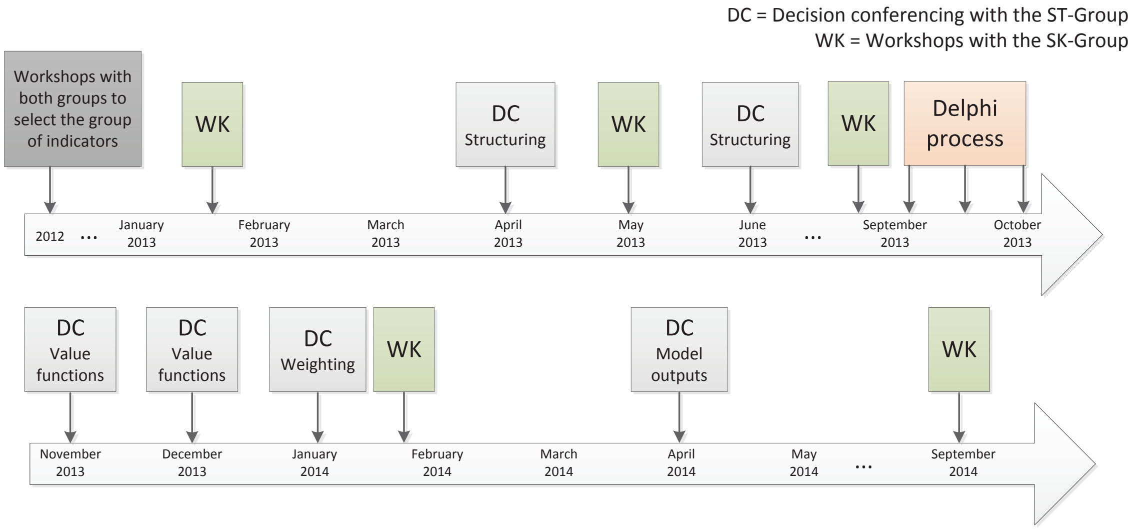


Fig. 3. Timetable of the process.

3.3.1 Design of a Modified Delphi process with MACBETH

In the context of evaluating population health, a value function captures how changes in performance in one evaluation criteria contribute for the health of a population. Value functions have four common shapes [64, 65] linear, concave, convex, and S-curve. By assuming that preferences are monotonically increasing, these four shapes can be described as:

(1) the linear value function has constant returns to scale, i.e. each increment of performance is equally valuable;

(2) the concave value function has decreasing returns to scale, i.e. each increment of performance is less valuable than the preceding increment;

(3) the convex value function has increasing returns to scale, i.e., each increment of performance is more valuable than the preceding increment;

(4) the S-curve can have increasing, then decreasing, returns to scale (a convex and then a concave curve) or have decreasing, then increasing, returns to scale (a concave and then a convex curve).

Note that, typically, only monotonic value functions should be considered, since, as Belton and Stewart ([42], p.137) state "a non-monotonic value function is often an indication that the proposed measure actually reflects two conflicting values", implying a need to revise the value tree.

In the literature, several authors [41, 43, 64, 65] state that before assessing a value function it is desirable to check its shape. In fact, "Sometimes these qualitative considerations restrict the shape of the function so much that little more elicitation (…) is required" ([43], p.237). Nevertheless, as far as we are aware, there is no questioning protocol available in the literature to perform this task. Hence, by exploiting the use of the MACBETH, we propose a protocol of questions about differences in attractiveness between different performance levels, which allows determining the shape of the value function for each evaluation criterion. To collect and collate the opinion of the SK-Group about the most appropriate type of value function for each criterion, we designed a modified Delphi process. We name it a modified Delphi process since it frames a Delphi process [50] with the MACBETH multicriteria approach.

Several studies (for e.g. [66], [67] and [68]) have reported difficulties associated with Delphi processes associated with: being time consuming and requiring participant commitment, as typically they are used to reach consensus, which can force, in some cases, an apparent convergence of responses by conformity pressures [66]. To overcome these problems, we designed a Delphi process with only two rounds to define the shape of the value functions, where the main goal is not to reach consensus but to acquire the opinion of the SK-Group, through a structured process, about the shape that the group considered most appropriate for each criterion. Therefore, the experts are consulted twice to, on one hand, give them opportunity to reconsider their answer, aided by the information they receive from the rest of the experts (to some extent promoting a convergence of opinions); and, on the other hand, avoiding a time consuming process since the main goal is not to reach consensus, but to provide valuable information to help the ST-Group to construct the value model. The modified Delphi process was conducted by neutral facilitators [50] (two of the authors of this article) that provided controlled feedback, informing the group members of the opinions of their anonymous colleagues. The SK-Group (composed of 19 members[1]) was divided into three smaller groups according to the expertise and skills of each expert (two groups with six members and one with seven). Each of these groups was responsible to provide judgments for a set of criteria related with their area of knowledge and experience.

The first task in the design of the modified Delphi process consisted in developing an online platform (see Fig.4), in which each expert could have access a simple protocol of questions that allowed determining the shape of the value function for each evaluation criterion. The web platform used the MACBETH approach and was built within the WISED decision support system [61]. This protocol of questions consists of:

(1) First, for each evaluation criteria (for instance, "Access to pharmaceutical care"), fix the "Best" and "Worst" levels of performance observed in the descriptor (i.e., in the "number of pharmacies per 1000 inhabitants") in the three periods under analysis (1991, 2001 and 2011 in our case); then find two intermediate levels equally spaced in performance - for example, for the criterion "Access to pharmaceutical care", the best of the three years is 1.5 pharmacies per 1000 inhabitants and the worst is 0 pharmacies per 1000 inhabitants; consequently, the two intermediate (L1 and L2) levels are 1 and 0.5 pharmacies per 1000 inhabitants, respectively. Then, the expert is asked to qualitatively judge the difference in attractiveness between consecutive performance levels, by using the MACBETH qualitative scale: no difference, very weak, weak, moderate, strong, very strong and extreme. Hence, each expert has to answer to three questions for each evaluation criteria.

(2) The answers of the expert allow for determining the shape of the value function. For instance, regarding the same criterion, the answer of the expert may be compatible with a concave, convex, linear or s-shaped value function (see all possible value functions for this criterion in Fig. 5): if the expert considered that the difference in attractiveness between the "Worst" and L1 is *moderate,* between L1 and L2 is *weak* and between L2 and "Best" is *very weak*, it is possible to conclude that for this expert the value function should be concave; if the expert considered that the difference in attractiveness between the "Worst" and L1 is *moderate,* between L1 and L2 is *strong* and between L2 and "Best" is *extreme*, it is possible to conclude that for this expert the value function should be *convex*; if the expert considered that the difference in attractiveness between the "Worst" and L1 is *moderate,* between L1 and L2 and between L2 and "Best" is also *moderate*, it is possible to conclude that for this expert the value function should be linear; finally, if the expert considered that the difference in attractiveness between the "Worst" and L1 is *moderate,* between L1 and L2 is *strong* and between L2 and "Best" is *moderate*, it is possible to conclude that for this expert the value function should be s-shaped (a curve that is first convex and then concave).

[1] The SK-Group includes participants with a background on geography, territorial planning, environment, economics, health professions and policymaking.

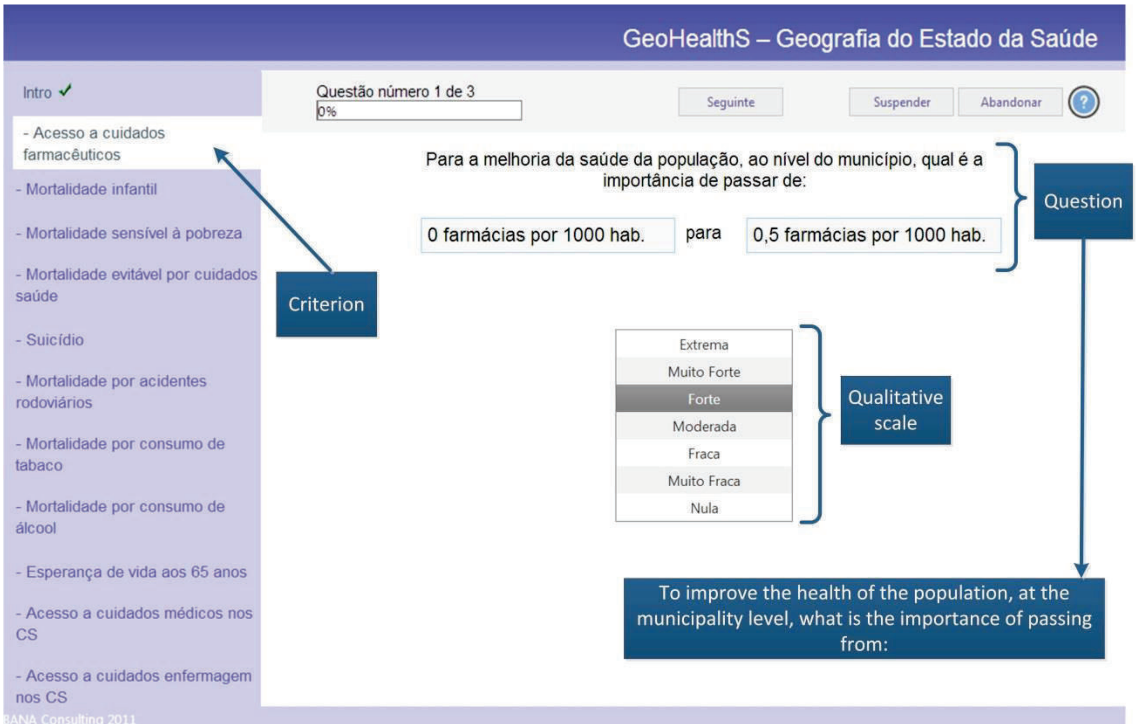


Fig. 4. Online platform designed with the WISED DSS for the modified Delphi process.

Then, after implementing the web platform, it was possible to launch the Delphi process, that was organized as follows:

(1) In a kick-off meeting, the facilitators explained in detail the modified Delphi process, the protocol of questions and how this questionnaire was used to assess the shape of the value function, and the process deadlines; scientific evidence about each criterion and a script about the Delphi process was also delivered to each expert.

(2) Then each expert received via e-mail a password, username and instructions to access to the online platform; in this online platform each member of the SK-Group answered to the aforementioned questionnaire, using the MACBETH qualitative scale.

(3) Based upon this questionnaire, the type of value function that matched the experts' answers was then determined by the facilitators and this ended the first round of the modified Delphi process.

(4) In the second round, a report giving feedback to each of the experts about the results of the first round of the modified Delphi process was prepared and sent to the experts via email, giving opportunity for them to revise their answers. Additionally, experts were asked to justify why they changed or maintained their answers. An example of this report is exemplified in Fig. 5, in which the expert revised his opinion, by ticking the new type of value function. This ended the second round of the Delphi process.

(5) Finally, after these two rounds, a final report with the results of the modified Delphi process was elaborated and sent to the members of the ST-Group. This report expressed, for each criterion, the level of agreement for each type of value function and a summary of the experts' justifications. In Fig. 6 it is displayed the final report of the Delphi process for the criterion "Access to pharmaceutical care", to which all the experts agreed that the value function should be concave; Fig. 7 displays the final report for the criterion "Mortality due to tobacco consumption" in which four of the six experts considered that the value function should be linear. In both reports it is also shown the expert's justifications regarding the chosen type of value function.

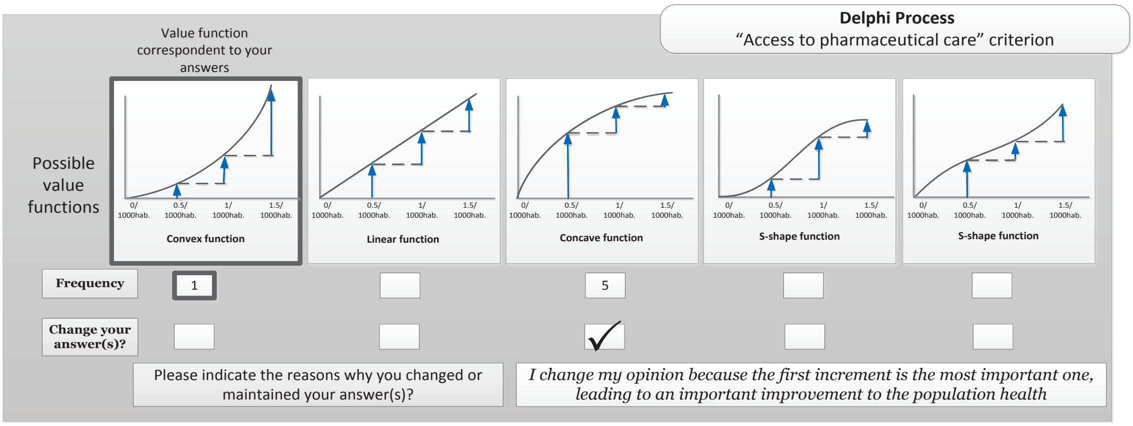


Fig. 5. Example of the feedback report for the criterion "Access to pharmaceutical care"; (this criterion was evaluated by a group of 6 experts).

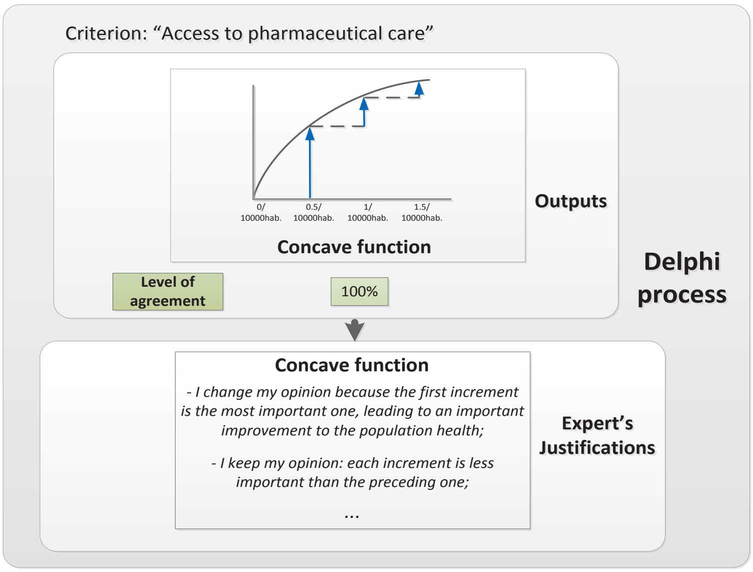


Fig. 6. Final report of the Delphi process for the criterion "Access to pharmaceutical care"; this criterion was evaluated by six experts.

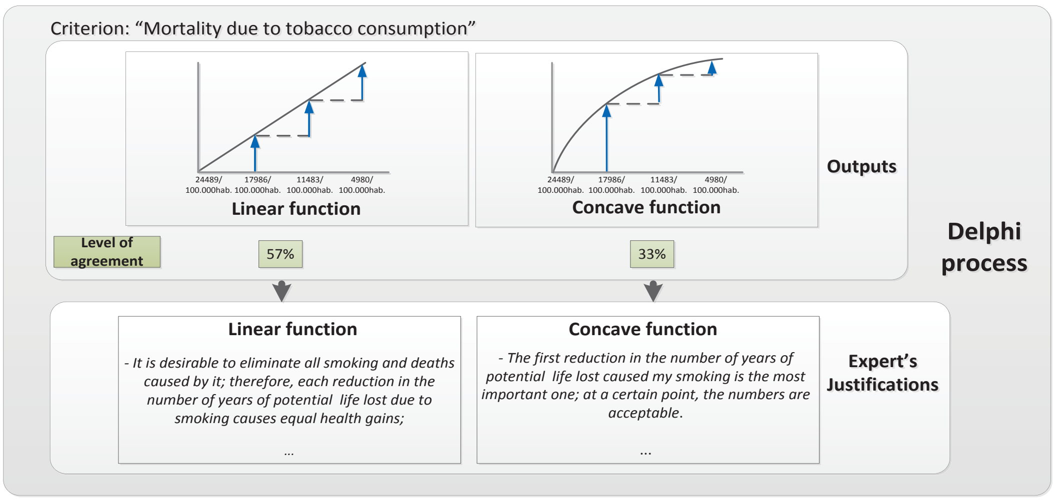


Fig. 7. Final report of the Delphi process for the criterion "Mortality due to tobacco consumption"; this criterion was evaluated by six experts.

3.3.2 Design of decision conferencing with MACBETH to build value functions

With the ST-Group, in a series of decision conferencing workshops, and with the support of M-MACBETH, the modified Delphi process results were analyzed and a value function was assessed. In this stage, first a final report with the Delphi process outputs was sent to the ST-Group for analyses, being then discussed in a decision conferencing meeting. For instance: 1) the members of the ST-Group agreed that a concave function was appropriate for the criterion "Access to pharmaceutical care" (see Fig. 6) because, after a certain level of availability of pharmacies per capita, the added value of an extra pharmacy is almost negligible; 2) and agreed with a linear value function for the link between "Mortality due to tobacco consumption" and population health (see Fig. 7) as they regarded that each decrease in the number of years of life lost caused by smoking equally contributes for population health.

In the case of linear value functions, it was straightforward to determine the mathematical expression of the value function for each of the evaluation criteria. In the other cases, an iterative and interactive process was applied to build a value function with the MACBETH approach. For instance, following Fig. 8 (continuing the example with the ''Access to pharmaceutical care" criterion), the ST-Group started to compare the difference in attractiveness between consecutive performance levels, i.e. between "Worst" and L1, L1 and L2 and L2 and "Best", filling the first diagonal of the M-MACBETH matrix (with judgements in line with a concave function); further judgements were also answered by the group (for example the difference in attractiveness between L1 and Best was also assessed). With this procedure, the MACBETH matrix of judgements was fulfilled with qualitative judgements. Then, with the support of M-MACBETH, a concave value function compatible with the judgements of the group and that respected the ''delta property'' was assessed. The ST-Group considered relevant to use value functions that respected the "delta property" as it reflects a ''constant trade-off attitude'' along the curve [52], meaning that the group is willing to give up, for example, doctors in hospital care to increase the number of pharmacies; and if the group accepts to incur *the same* losses to improve from "Worst" to 0,4 pharmacies as to improve from 0,4 to L1 pharmacies, then these preferences will hold for every sub-interval of the curve.

For each evaluation criterion, once the ST-Group has provided its qualitative judgments, the M-MACBETH software assists in computing a quantitative value scale that is then eventually adjusted and validated by the group.

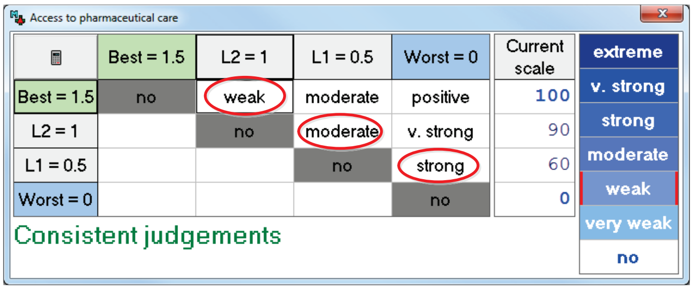


Fig.8. Qualitative judgements for building a value function for the criterion "Access to pharmaceutical care" with M-MACBETH.

3.3.3 Design of decision conferencing with MACBETH to assess the hierarchical weights

As highlighted in Section 2, the use of inappropriate weighting procedures is a common problem in the construction of population health indexes. To avoid this type of problem, it was adopted a bottom-up weighting procedure with the MACBETH approach to determine the criteria and area weights that adequately reflect value trade-off judgments of the ST-Group; and this was supported by a new hierarchical version of the M-MACBETH software. This procedure consisted on a simple protocol of questions that were answered by the ST-Group in a decision conferencing meeting.

To illustrate the adopted procedure, consider the area of concern "Life Style" with three evaluation criteria (see Fig.9). In order to weight these criteria, the ST-Group was introduced to the concept of qualitative swing weighting and was asked to judge, in decreasing order of relative importance, the swing from the "base_2011" to "'top10%_2011" on the three criteria. For instance, the ST-Group considered that the swing from the "base_2011" to "'top10%_2011" was more important in the criterion "Alcohol consumption", followed by the swing in the criterion "Obesity" and finally by the swing in the criterion "Teenage parenting" (see Fig.10). Then, other judgements were assessed for each swing and for each pair of swings, by posing questions as: "How much more important would be the improvement of performance from "base_2011" to "top10%_2011" on "Obesity" than the improvement from "base_2011" to "top10%_2011" on "Teenage parenting''? For example de group considered that the improvement of performance from "base_2011" to "top10%_2011" on ''Obesity'' is viewed as strongly more attractive in terms of life style as a similar improvement in the ''Teenage parenting''. With these type of judgements a MACBETH matrix was populated (see Fig. 11), and the M-MACBETH hierarchical software proposed weights to the criteria that were adjusted and validated by the ST-Group.

This bottom-up process is then repeated for all the evaluation criteria and for all the levels of the (hierarchical) value tree, and with the support of the hierarchical version of the M-MACBETH software, allows determining criteria and area weights.

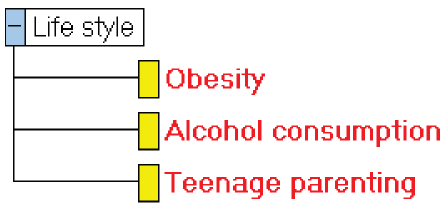


Fig. 9. Tree of the area of concern "Life Style" with three evaluation criteria in M-MACBETH.

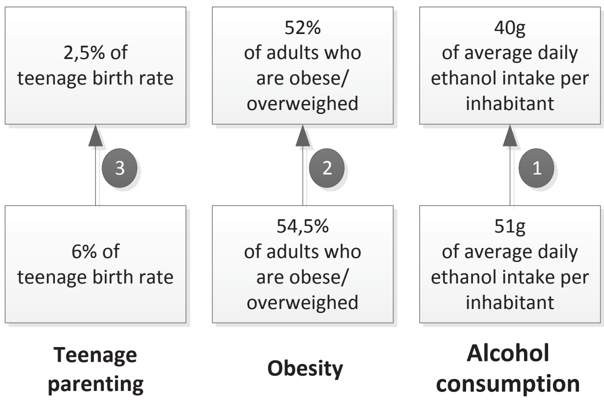
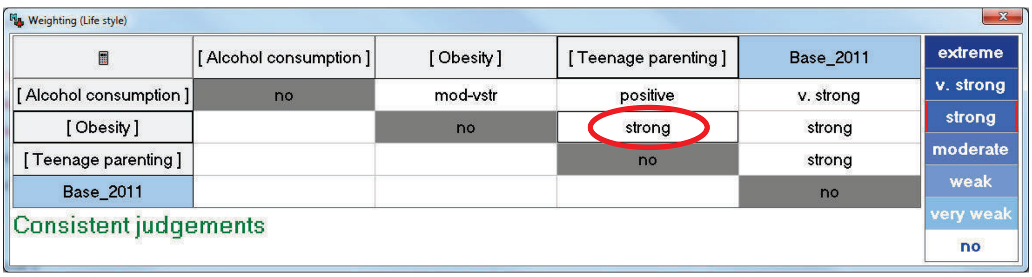


Fig.10. References "Top10%_2011 and "Base_2011" of the criteria within the "Life Style" area and ranked swings.



Weighting (Life style)

	[Alcohol consumption]	[Obesity]	[Teenage parenting]	Base_2011
[Alcohol consumption]	no	mod-vstr	positive	v. strong
[Obesity]		no	strong	strong
[Teenage parenting]			no	strong
Base_2011				no

Consistent judgements

extreme, v. strong, strong, moderate, weak, very weak, no

Fig. 11. Matrix of MACBETH weighting judgements for the area of concern "Life Style" in M-MACBETH.

3.4 *Model outputs and validation*

Fig. 2 illustrates how the model outputs can be integrated within a "tableau-de-bord" structure [46] where it is possible to analyse, over time, the performance and the (population health) value profile of each municipality within and across areas, and the aggregated value of each municipality; this permits to visualize the areas of concern in which each municipality demands higher attention, to observe the evolution of population health for each geographic area and across time, as well as to compare in each year and across time the health of the population of different municipalities. Moreover, the value of each municipality in each area and in overall terms can be analysed in terms of their distance to the ‘‘top10%’’ and the ‘‘base’’ references of the respective year. Finally, the model outputs provide an overall picture of the health of the population in each municipality, allowing health decision-makers and policy-makers to visualize geographic health inequalities within and across municipalities over time.

According to Kaltenthaler et al. [10] health indexes need to undergo extensive testing, with the aim of ensuring the validation and reliability of the model outputs. Therefore, to ensure that the model was “requisite” i.e. that could be satisfactory used to evaluate population health at the municipality level, the ST-Group extensively analysed the model outputs (municipality’s population health profiles, disaggregated and aggregated, and over time) for nine representative municipalities and discussed these outputs in a decision conference. That discussion has led to some model adjustments, and the ST-Group is now making a final review of the model. At this stage, the members of the SK-Group are also being consulted to give feedback regarding their views on the model outputs. Analyses of model outputs are further being enabled by the visualization of results in geographic information system.

4. Results of the application of the multicriteria model to the Portuguese case

This section presents selected features and results of the application of the proposed framework to build an index to evaluate population health at the municipality level in Portugal over the past twenty years (in the years of 1991, 2001 and 2011). These are still preliminary results, as the model may still be subject to some final adjustments.

4.1 Value tree

The hierarchical structure of the model adopted to build the health index is depicted in the value tree of Fig. 12. The areas of concern are specified by a set of 44 evaluation criteria on which the health of the population should be appraised. For example, in the “Life Style” area of concern, three criteria were set. The value tree was considered concise and complete, incorporating all the relevant aspects that both groups considered important to evaluate population health at the community level.

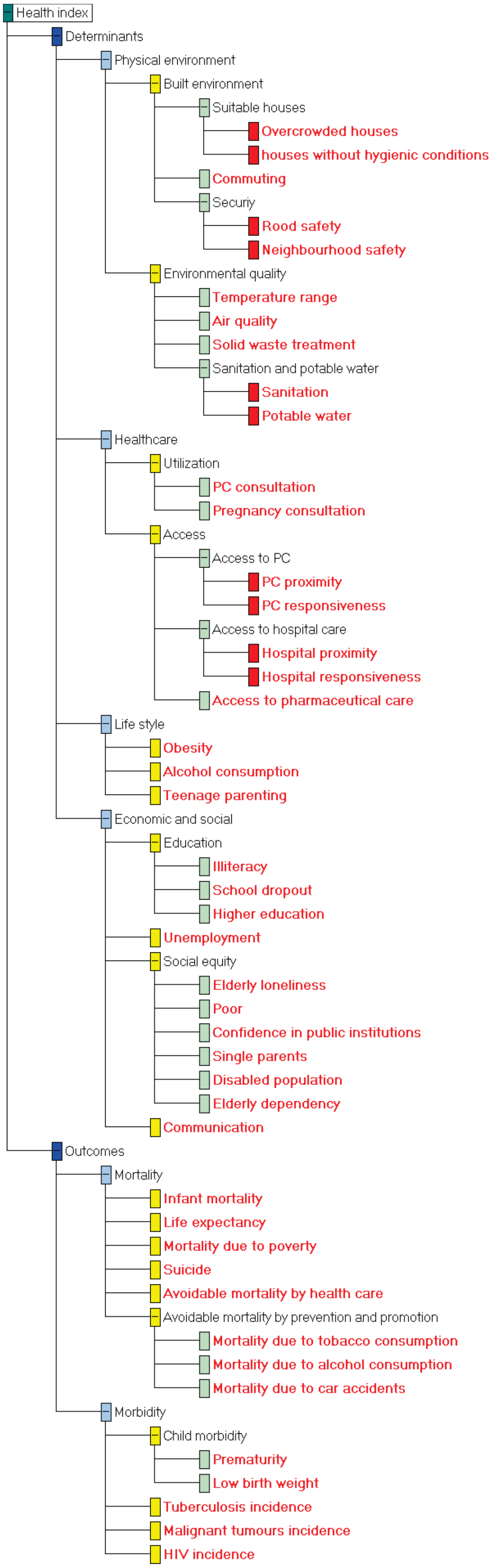


Fig. 12. Value tree with two main areas of concern: health determinants and outcomes. Evaluation criteria are depicted in red.

4.2 Descriptors and value functions

A descriptor of performance was built for each evaluation criterion, integrating an indicator or several indicators. Some examples of descriptors are displayed in Table 1.

Evaluation criteria	Criteria description	Descriptor of performances
Alcohol consumption	is concerned with promoting responsible drinking habits with the aim of reducing diseases associated with alcohol consumption	Average daily ethanol intake per inhabitant
Obesity	is concerned with promoting healthy eating habits and physical exercise with the aim of reducing diseases associated to obesity and overweight	Percentage of adults (age 20 years and over) who are obese or are overweighed
Teenage parenting	is concerned with the adoption of responsible sexual behaviours to reduce the risk of sexually transmitted diseases; additionally teenage mothers and their babies are risk groups with social and health problems that need to be taken into account	Teenage birth rate (%)
Tuberculosis incidence	accounts for the incidence of tuberculosis in the population	Number of new cases of tuberculosis per 100.000 inhabitants
Malignant tumours incidence	accounts for the incidence of malignant tumours in the population	Number of new cases of malignant tumours per 100.000 inhabitants
HIV incidence	accounts for the incidence of HIV in the population	Number of new HIV infections per 100.000 inhabitants

Table 1 – Criteria and respective descriptors of performance.

The construction of value functions followed an interactive and constructive 2-phase process, with the first phase consisting on the modified Delphi process framed with MACBETH. This process produced information for each criterion in the form depicted in Fig.s 6 and 7, as earlier described in section 3.3.1. Table 2 displays the level of agreement achieved in the modified Delphi process, showing a full adherence among experts (zero dropout rate among panel members) and a level of agreement on the type of value function higher than 57% was obtained for more than 70% of the criteria.

Level of agreement on the type of value function	Evaluation criteria
= 100%	9
≈ 83% (5 of 6 experts)	6
≈71% (5 of 7 experts)	7
≈ 66% (4 of 6 experts)	8
≈ 57% (4 of 7 experts)	5
Other cases	9

Table 2 – Overview of the results of the Delphi process.

Finally, based upon the views of the ST-Group and on the procedures previously described, value functions were built with the SK-Group. Fig. 13 depicts the final value function for the criteria "Access to pharmaceutical care", "Utilization of primary care services", "Obesity" and "Prematurity". It is worth noting that for the "Utilization of primary care services" criterion the value function has a ceiling indicating that above 5 consultations per inhabitant, the added value of an extra consultation for the improvement of population health is zero; for the "Obesity criterion" it was considered that each reduction in the number of people that are obese is equally important for the health of the population; and for the "Prematurity" criterion it was considered that the reduction on pre-term babies is more important when the municipality has a high level of prematurity.

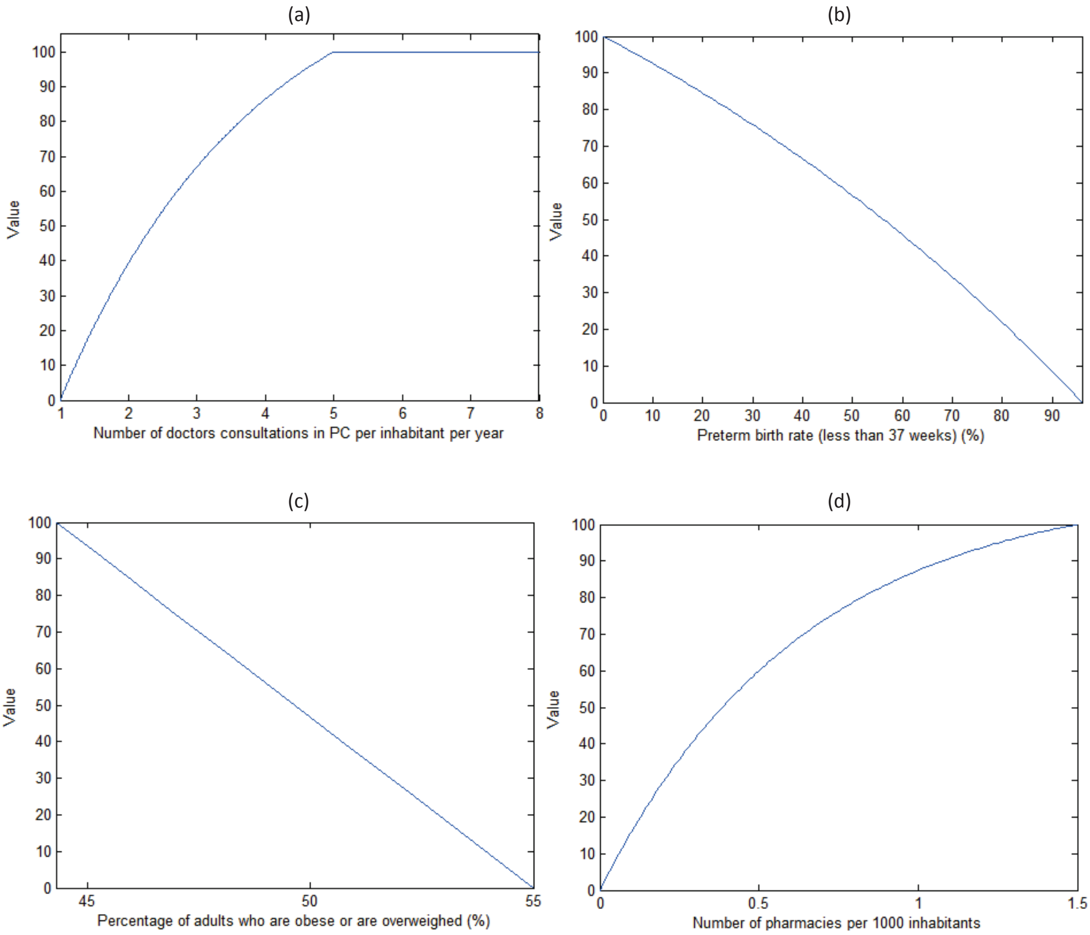


Fig. 13. Value functions for the criterion (a) "Utilization of primary care services", (b) "Prematurity", (c) "Obesity" and (d) "Access to pharmaceutical care".

4.3 Weighting criteria and areas of concern

The weights of the criterion within the area of concern "Life Style" are depicted in Table 3, while Table 4 displays the weights of the areas of concern within the two top-level areas of concern: "Determinants" and "Outcomes". These weights were the results of using the hierarchical version of M-MACBETH and should be interpreted as follows: the fact that the ST-Group agreed that the weight of the area of concern "Economic and social" is the double of the weight of the area of concern "Physical environment" substantively means that if it was possible to change the performance of a municipality from the ''base_2011'' to the ''top10%_2011'' in all the ''Economic and social'' criteria, this change in the health of the population of the municipality would be seen as twice more attractive than the possibility of changing the performance of a municipality from ‘‘base_2011’’ to the ‘‘top10%_2011’’ in all the criteria within the ‘‘Physical environment’’ area.

Criteria	**Criteria weight** (%)
Alcohol consumption	55
Obesity	40
Teenage parenting	5

Table 3 – Weights of criteria within the area of concern “Life Style”

Area of concern	**Area weight** (%)
Determinants	52
Economic and social	44
Physical environment	22
Life Style	15
Healthcare	19
Results	49
Mortality	31
Morbidity	69

Table 4 – Area weights

4.4 Key outputs from evaluating population health at the municipality level in Portugal

This section presents some preliminary outputs of the multicriteria model that will be used to evaluate population health at the municipality level in Portugal. Table 5 depicts population health scores of nine municipalities in several areas of concern and in overall terms for the year 2011. The evolution of population health across time for the municipality “Coimbra” is shown in Table 6. Examples of insights taken from Tables 5 and 6 are: population health has been improving since 1991 in the municipality of Coimbra, although this evolution hides a worsening in the “Economic and social” determinants. This partly reflects the impact of the economic crisis that Portugal has been suffering in recent years. Also, in 2011, the population health scores in several areas of concern and for several municipalities are below the “Base” reference level of the year, which shows which municipalities in each area of concern demand for higher attention.

	Mortality	Economic and social	Determinants	Results	Index (Overall value)
Freixo de Espada à Cinta	15,8	-53,4	-15,3	-5,7	-10,7
Oeiras	1,2	49,5	38,7	-26,9	7,2
Lisboa	-68,2	9,2	10,6	-68,1	-27,2
Setúbal	-46,5	-4,8	3,5	-13,4	-4,6
Porto	-88,1	-59,1	-11,8	-79,9	-44,5
Vila Nova Famalicão	40,8	27,7	5,1	61,8	32,3
Aljezur	-5,7	-17,3	-53	-4,3	-29,7
Coimbra	32,6	52,1	36,2	29,5	33,0
Mourão	-59,5	-183,5	-95,5	-67,6	-82,1

Table 5 – Value scores of nine municipalities in selected areas of concern and in overall terms in 2011.

<table>
<tr><th></th><th colspan="2">Mortality</th><th colspan="2">Economic and social</th><th colspan="2">Determinants</th><th colspan="2">Results</th><th colspan="2">Index (Overall value)</th></tr>
<tr><td rowspan="2">1991</td><td colspan="2">-96,7</td><td colspan="2">78,9</td><td colspan="2">29,9</td><td colspan="2">-71,4</td><td colspan="2">-15,4</td></tr>
<tr><td>7,0</td><td>-175,4</td><td>119,7</td><td>-12,4</td><td>106,3</td><td>-30,5</td><td>35,3</td><td>-146,1</td><td>74,5</td><td>-82,2</td></tr>
<tr><td rowspan="2">2001</td><td colspan="2">-8,3</td><td colspan="2">77,1</td><td colspan="2">42,5</td><td colspan="2">-22,3</td><td colspan="2">11,4</td></tr>
<tr><td>69,5</td><td>-56,4</td><td>120,5</td><td>6,9</td><td>114,7</td><td>-1,4</td><td>122,9</td><td>-22,9</td><td>118,6</td><td>-11,7</td></tr>
<tr><td rowspan="2">2011</td><td colspan="2">32,6</td><td colspan="2">52,1</td><td colspan="2">36,2</td><td colspan="2">29,5</td><td colspan="2">33,0</td></tr>
<tr><td>100</td><td>0</td><td>100</td><td>0</td><td>100</td><td>0</td><td>100</td><td>0</td><td>100</td><td>0</td></tr>
</table>

Base_year Top10%_year

Table 6 – Variation of value scores of the municipality Coimbra for several areas of concern and across time.

It is worthwhile noting that an analysis made across areas and in overall terms may mask some important problems regarding population health [8, 9, 20], as a result of the compensatory nature of the multicriteria model. This is why the ‘‘tableau de bord’’ (see Fig. 2) offers information concerning all evaluation criteria, allowing to evaluate population health within and across areas of concern, providing information about critical situation that are not mask by the aggregation procedure. As an illustration, Table 7 shows that although Coimbra has a positive score in the “Economic and social” area of concern, special attention should be given the “Single parent families” criterion.

Evaluation criteria	**Value scores**
Unemployment	60,0
Illiteracy	92,3
Single parent families	-96,2
Loneliness in older people	1,5
Poor	36,1
Disabled population	34,2
...	...
Economic and Social	52,1

Table 7 – Scores of the municipality of Coimbra (2011) in some criteria belonging to "Economic and Social" area.

5. Discussion

The proposed value-based health index has been applied to evaluate the population health of Portuguese municipalities over the past 20 years and is being implemented in a Web Geographic Information System (WEBGIS); the “tableau-de-bord” structure of the model outputs eased the construction of the WEBGIS in which policy-makers, health-stakeholders and all community members can consult the model outputs, thus facilitating the transmission and communication of variations in population health and of geographical health inequalities in the Portuguese territory.

Overall, the proposed index can be useful in detecting patterns of illness and disease and health disparities, in allowing for a wide range spatial-temporal analysis and in being the starting point for policy-makers and planners investigating critical areas of concern, helping them to propose remedial health policies that can help to address the problems found in each municipality. Future research can explore the use of the model to simulate the impact of health policies on population health. Complementarily, resource allocation models [69] can be proposed to assist which combination of policies has the potential to maximise population health and to decrease health inequalities.

This study contributes to literature by showing how decision analysis methods can be used to construct a population health index within a sound theoretical framework, combining evidence with participatory processes involving experts. With regard to the use of participatory methods, a modified Delphi process was applied to compile the opinion of the SK-Group about the type of value function that was most suitable for each criterion. Two aspects regarding the design of this process deserve special attention. Firstly, the zero drop-out rate among experts contributed to the reliability of outcomes [70, 71] of the Delphi process. We think that the adherence of the experts was achieved by having a process with only two rounds which avoided a feeling of fatigue among experts, and by the use of simple and clear protocols of questioning (based upon qualitative judgements with MACBETH) combined with a friendly web platform to collect experts' judgements. We deem as critical the realization of a meeting in which the whole process was explained and discussed. Secondly, by avoiding the need for having a consensus in the Delphi process - through the use of decision conferencing with the ST-Group - , there was no need to force experts to have middle-of-the-road opinions (avoiding what the literature describes as conformity pressure [66]). Resorting to the decision conferencing process, it was possible to construct a model on-the-spot to assist the ST-Group in thinking more clearly about population health and its multiple dimensions. As Phillips and Bana e Costa ([47], p. 54) state decision conferencing allows to build a model that "it is less likely to be perceived by participants as a 'black box,' which helps to gain confidence in model results". Differences in opinion and hesitations were accommodated with the MACBETH approach, with all members of the ST-Group accepting the final results.

The index-building process was time-consuming given the large number of criteria and the amount of information required about population health. Nevertheless, although time consuming, the views of the participating experts were critical for building a requisite model; experts emphasized that the process of model development enabled learning and potentiated a higher acceptance of the model to be used for evaluating population health. Finally, an important feature of the proposed framework was its iterative and dynamic nature, which lead to the creation of a reliable "requisite" tool that underwent validation tests [10] and had theoretically sound foundations [11].

Several challenges remain regarding the communication of features and outputs of the model, including: how to best communicate the model results, using a scale of score that avoids negative values (which may generate political reactions); and how to make sure that the model users (e.g. citizen and policy-makes) understand the model assumptions and recognize that the model reflects current views to analyse population health in previous years. Future research is also needed for constructing a colour categorization system to support the elaboration of maps in which each category of colour should have an important and substantive meaning; and for defining procedures for performing sensitivity and robustness analyses in the measurement of population health [72].

The proposed social-technical process is to be further developed and extended to build a value-based population health index to assess population health in European regions, within the scope of the EURO-HEALTHY project funded by the European Commission, to be started in 2015.

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