Designing a multi-methodology to analyse which policies have the potential to promote health and health equity in the context of a population health index

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Abstract — *Population health indexes have been developed with the aim of measuring the health of populations at different geographical levels. These indexes inform which geographic areas may benefit from health improvements, thus representing a valuable tool to evaluate which combinations of policies have the highest potential to promote population health and reduce health inequities. Nevertheless, there is a lack of studies in this area.*

Departing from a comprehensive population health index that characterizes the health of a population through multiple dimensions, this thesis develops a multi-methodology to identify which policies have the highest potential to promote health and equity for the population of a set of regions, by following these steps: a) starts with the population health index; b) then, the policy objectives that are worth to be pursued are selected; c) and using clustering methods, regions with similar health patterns in multiple dimensions and that may benefit from similar types of policies are identified; d) afterwards, departing from these clusters, a sample of relevant policies with potential to improve the objectives is defined; e) and the impact of these policies is measured; finally f) multiobjective mathematical programming models are developed so as to determine which combinations of policies have the highest potential to improve the selected objectives over these regions; g) followed by the results communication.

This multi-methodology is applied to data from the GeoHealthS project – a project in which a population health index of the Portuguese municipalities was built to analyse health variations across the Portuguese territory.

Keywords — Population health; health policy; policy assessment; quantitative methods; multi-methodology.

I. Introduction

Population Health Indexes (PHI) have been developed with the aim of measuring the health of populations at different geographical levels. These indices inform which geographic areas may benefit from health improvements, thus representing a valuable tool to evaluate which combinations of policies have the highest potential to promote population health and reduce different types of health inequities. Nevertheless, there is a lack of studies in this area.

The objective of this work aims to go further, by constructing a novel multi-methodology, which was designed to analyse and assess which policies have the highest potential to promote health and health equity in the context of a population health index. In particular, this multi-methodology covers multiple aspects, from the selection and operationalization of the population health objectives; to the assessment of the status quo of the index using clustering techniques; and to the use of mathematical programming models for the selection of policies and assessment of their impact on the index's dimensions and regions.

Additionally, the importance of this multi-methodology comes from the fact that there is the need for robust quantitative methods to inform decision makers in their process of selection of policies to mitigate health inequities between citizens, as well as to promote policies that achieve the highest health gains, helping policy-makers in their decisions of how to construct a more homogenous and fair Portugal in terms of population health. This is especially relevant within the current context of economic and financial crisis, where combating health inequities constitutes one of the greatest challenges faced by public health administrators. In fact, several countries are currently facing a considerable lack of resources that are not enough to meet these current challenges, thus increasing the importance of this type of quantitative methods to inform the selection of the most relevant policies, having in mind that the goal of this multi-methodology is to support decision makers and not substitute them. However, it was not possible to have these interactions with decision makers during this thesis Also, the work developed under this study aims to go further than the actual state-of-the-art, by providing a set of tools for the evaluation of policies based in a population health index.

In order to test the multi-methodology, several case studies will be presented using the GeoHealthS index [1], a population health index of the Portuguese Municipalities. Being developed with a generic character, the proposed multi-methodology have potential to be used to inform the analysis of policies to improve health and health equity across European regions, within the multi-methodology scope of the Euro Healthy project [2].

II. Context

A. Population Health

Population Health is a key concept in the context of this work. However, there is a lack of consensus in the literature around a precise and unique definition of what is Population Health. Along the years, multiple authors have proposed different definitions, such as The Public Health Agency of Canada [3], Young [4], Dunn & Hayes [5] and Kindig & Stoddart [6], being the most interesting definition for this work from Kindig [7], that defines it as *"Population Health use many terms, such as outcomes, disparities, determinants [...] establishing clear and definitive causal relationships between broad determinant categories or specific programs and policies that predict with relative certainty their short- and long-term impacts on a variety of Population Health outcomes of interest… What is the optimal balance of investments (e.g., dollars, time, policies) in the multiple determinants of health (e.g., behaviour, environment, socioeconomic status) over the life course that will maximize overall health outcomes and minimize health inequities at the population level?"*

Since Population Health lacks a clear definition, the term is under some critiques, such as for being limited to macro-level analysis. Though, the scope of the Population Health is the overall health of a population, so it is expected to follow a more holistic view [6].

A characteristic of Population Health is being a combination of the concepts of population and health. Population is defined as a group of individuals, which can be organized into multiple units, such as geographic units (e.g. cities, regions and countries) or by specific characteristics (e.g. ethnicity, religion and gender). Also, regarding the concept of Health, many definitions exist and are used, such as being the state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity [7].

Nevertheless, some key concepts can be clearly linked with Population Health, such as determinants, which is a common term in disciplines such as medicine, epidemiology, economics and sociology [7].

B. Population Health Indexes

Population Health Indexes are comprehensive and transparent tools, that can be applied for the characterization and monitoring of population's health, both in a global way or in different areas of concern (e.g. economics, social equity, environment, health care, mortality and morbidity), covering specific periods of time (e.g. a period of 20 years) and space (focusing on different geographical levels, such as countries, regions, municipalities, metropolitan areas, etc.). They have been used in several contexts to evaluate population health in multiple dimensions, with the objective of informing decision-makers of how variations in health determinants and outcomes result in the variation of the health of the populations [1].

Some examples of population health indexes include the Canadian Index of Well-Being, developed by the University of Waterloo [8]; County Health Rankings, developed by the Wisconsin Population Health Institute of the University of Wisconsin [9]; and the GeoHealthS index, that will further detail, since it will be the basis for the case studies of this work.

C. GeoHealthS Index

The main objective of the project Geography of Health Status – An application of a Population Health Index in the last 20 Years (GeoHealthS) was to evaluate the health of the Portuguese population over the last 20 years through the construction of a Population Health Index (called INES) of the Portuguese municipalities [1].

This population health index was built through a socio-technical process. The social side integrates evidence from literature and research results with the views and opinions of stakeholders, such as policy makers and experts from a variety of disciplines, using participatory methods (Delphi panels and decision conferences). The technical side includes multi-criteria decision analysis methods (MACBETH approach) [1].

The process resulted in INES, that features 6 sub-sections (areas of concern), corresponding to the socio-economic status, physical environment, lifestyle, health care, mortality and morbidity, joining together 43 dimensions with one or more indicators assigned, in order to describe the performance of each of the 279 municipalities in mainland Portugal in that respective dimension, at three different moments of time (1991, 2001 and 2011). Figure 1 shows the final areas of concern of the GeoHealthS index [1].

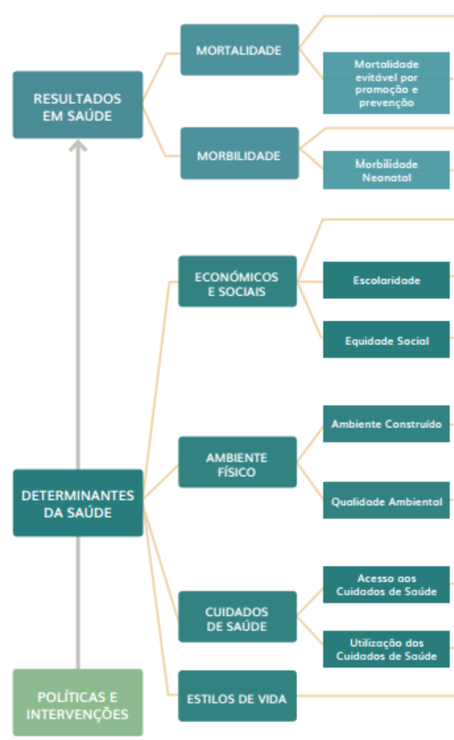

Figure 1 – The GeoHealthS index (in Portuguese as the original form) (54)

D. EURO-HEALTHY Project

In the sequence of the GeoHealthS project, a new H2020 project - the Euro-Healthy project - was initiated [2]. The EURO-HEALTHY (Shaping EUROpean policies to promote HEALTH equity) project has the main goal of advancing knowledge of policies that have the highest potential to enhance health and health equity across European regions. In order to fulfil this goal, a Population Health Index of 28 European countries, 273 NUTS II regions and with special focus on 10 metropolitan areas will be constructed. The evidence that will be used to construct this index takes into account multiple determinants and health outcomes of the past 15 years, including multiple dimensions: socio-economic, demographic change, lifestyle and health behaviours, physical and environmental indicators. Also, in the construction of this index, it will be used a multi-criteria model structure and participatory processes [2].

Since the multi-methodology proposed in this study plays an important role for understanding which regions have similar patterns and needs for health improvement, and then to understand how policies can improve health and inequities in different geographic areas, it is possible to argue that it has potential to be used within the Euro-Healthy project. Accordingly, it represents a potential tool to inform health-related investments at the EU, at both national and local government's levels.

E. Objective

The main objective of this work was to develop a multi-methodology that can be used to support the analysis of which combinations of policies have the highest potential to promote health and health equity. Particularly, by departing from the characterization of regions with similar pattern and needs of policies, policies can be analysed and compared in terms of their potential to promote health and equity across these regions. This multi-methodology should depart from a Population Health Index, which allows to understand how different factors contribute to population health, in a transparent and comprehensive way and based on sound methods.

III. Literature review

This study' goal is to develop methods so as to evaluate policies that improve the population health and reduce health inequity between regions, considering multiple objectives and using a Population Health Index as a starting point. However, there is a lack of literature on this topic, with no study combining evaluation of policies and the use of population health indexes, especially using quantitative methods to support and inform the decision-making process.

This section will be centred in the revision of useful concepts and methods that can be of value for the multi-methodology

A. Policies in Population Health

The objective of evaluating policies requires the definition of what is a policy. In the literature, these concepts have several definitions, but policy can be defined as a guide to action in order to change what would otherwise occur, including the decision about how to allocate and the amounts of resources. Policy sets priorities, and guides resource allocation [10].

Additionally, the way a policy is carried out in order to impact the health status, can be through very different implementation methods. Four categories of policy interventions may be presented: interventions targeting the worst-off; universal policy with additional focus on gap; 'redistributive policy'; and proportionate universalism [11]. These types of interventions are focused in the promotion of health gains and in the reduction of health inequities. Additionally, they require the establishment of groups, with these representing segments of the population with similar characteristics.

B. Methods for the evaluation and selection of policies

Several studies exist in literature to evaluate policies that promote health and equity, such as Oliveira et al. [12], Simpson et al. [13] or Brown [14], although there is a lack of studies using quantitative methods and in the scope of population health index. Though, there is a vast range of methods that have been applied with the goal of selecting policies, in general, and having the goal of promoting health and equity. Within the scope of those methods, clustering methods and mathematical programming models play a key role, being the ones selected to be detailed [15].

1) Clustering techniques

Clustering algorithms are unsupervised learning methods, which classify objects into clusters that share the same characteristics. Additionally, those clusters are constituted by a set of objects that are more "similar" among themselves, than to other clusters' objects [16].

A classical algorithm that may be used is the k-means algorithm, one of the most popular and used algorithm in the literature. The objective of the k-means algorithm is the partition of the objects in k clusters [16].

2) Mathematical programming models

The main feature of mathematical programming (MP) models is their optimization purpose of searching the optimal solution. So, in the end, the objective of MP models is to maximize or minimize the objectives (objective function in MP terminology).

This type of models share a common structure, which is constituted by four components:

- Decision variables – variables that are determined by the solution of the problem and, traditionally, cannot have negative values [17];
- Objective functions – describes in a mathematical statement the goal to be maximized or minimized, described as a function of the decision variables [17]. Typical examples of objective functions are the maximization of profits, minimization of costs or the maximization of utility [18];
- Constraints – limitations that restrict the possible solutions. These are a set of equalities of inequalities that have to be respected [17];
- Parameters –numerical values that are used to describe the problem. Changing these values can alter the final solution, allowing to experiment different problem inputs [17].

Moreover, mathematical programming models are very adequate to be used for the selection of policies. However, the optimal concept only applies in a straight forward way in single objective cases, e.g. desiring to reduce the mortality of a disease or desiring to improve the access to primary care. Though, when a multitude of objectives are added in a problem, the concept of optimality is harder to apply [19], e.g. in the case of desiring to have a major reduction in a disease mortality and to improve the access to primary care at the same time, there is no policy (hypothetically) that promotes both categories simultaneously. This leads to multiobjective programming models. These multiobjective models involve the simultaneously optimization of more than one objective function. These multiple objective functions may lead to the conflict between objectives. So, trade-offs have to be taken into account and decision makers should be leveraged in the specification of those trade-offs between objectives [19].

A possible solution to these trade-offs are weighting methods. The idea behind them is to first assign weights to each objective, and then aggregate them into a single objective function. Transforming the objective function into a linear problem, easy to solve [19]. Additionally, it is central to define properly the weights. In particular, the Portfolio Decision Analysis (PDA) is a useful method with sound theoretical and methodological basis, to contribute to the solution of these kind of problems. PDA consists in the application of decision analysis to the problems of selecting portfolios or subsets of alternatives, i.e. portfolios in this study are combinations of policies [20].

Mathematical programming models may be used to recommend which subset of portfolios of policies should be selected to optimize the objectives. In the literature exists a vast range of examples of mathematical programming models that deal with problems of having to promote health gains and equity, by optimizing multiple objectives, examples of this type of models are present in Koyuncu et al. [21], Smith et al. [22] Cho [23], Oliveira et al. [24] or Cardoso et al. [25].

C. Policy objectives

Two main types of policies objectives are relevant in this work, equity- and health gains-related objectives.

1) Equity

The concept of equity is common to many different disciplines. In this work, several of those areas were explored, more precisely health economics, public health and location allocation (field of operations research). The knowledge obtained was adapted to the particular context of using a population health index in order to evaluate policies. Also, one of the most relevant definitions of equity is from the World Health Organization: "*Equity in Health: (i) the absence of systematic or potentially remediable differences in health status, access to healthcare and health-enhancing environments, and treatment in one or more aspects of health across populations or population groups defined socially, economically, demographically or geographically within and across countries. (ii) a measure of the degree to which health policies are able to distribute well-being fairly.*" [26].

Other topic present in the literature, it is the common confusion between equity and equality. Although these two concepts are distinct, equality is indispensable in order to operationalize and measure equity. Equity is an inequality that is unjust and unfair, and requires the comparison how different groups are faring, for example comparing the best off group with the worst-off [27]. So, not all health inequalities reflect inequity, for example teenager are expected to be healthier than elderly, but this inequality is not unfair. Yet, differences in immunization levels by vaccination in some countries between men and women is a form of inequity [28].

In order to operationalize the objective of promoting equity in a population, a vast range of equity measures has been proposed and researched in the literature, especially in the literature of location allocation [19; 28] and health economics [29]. However, literature, under the context of population health index is scarce.

2) Health gains

Health gains are improvements in health indicators, and can be used as a reference for the respective evolution. Since, they express improvements in health results, may be translated in gains of years of life, reduction of the prevalence of diseases, etc. Especially relevant are the heath gains that arise from the capacity to intervene in avoidable cause by the use of policies [30].

In the population health indexes' context, dimensions cover a vast range of subjects (e.g. access to healthcare, unemployment, air quality…). So, the dimensions can be used to assess how well a region in that indicator is. Additionally, the impact of a policy may be assessed by the difference between the initial value and the value after the policy, being a type of health gains measure.

An example of use of health gains is in the Portuguese national health plan 2012-2016 (*Plano Nacional de Saúde*), where health gains are a major topic, since the plan has the responsibility of identifying health gains to be achieved by the Portuguese health system. So, in the elaboration of this plan, a set of performance indicator of health gains was defined for six main groups (mortality, mobility, incapacity, health system response and sustainability) [31]. But, compared to this plan and its health gains indicators, this study methods have several differences, being the main one the use of a population health index instead of less structured data like in the plan.

D. Motivation

As it can be concluded from this literature review, a key motivation for the development of this study was the scarcity of studies on methods that deal, in an integrated way, with the identification of regions with similar population health characteristics and that may benefit from similar policies as well as with the evaluation and selection of policies that have potential to improve population health and health equity in the specific context of a population health index. So, the main goal of this study is to close this research gap, by designing a multi-methodology to analyse which policies have the potential the promote health and health equity in the context of a population health index.

IV. MULTI-METHODOLOGY

This study' approach uses several methods throughout the different steps, with the objective of analysing which policies have the highest potential to promote health and health equity in the context of a population health index. This approach is in line with the definition of multi-methodology of Mingers, 1997 [32], which is defined as the utilization of more than one methodology within a single intervention and into a common framework [32]. In the context of this study, the intervention is composed by a set of steps in order to evaluate policies by their impact on a population health index.

The advantages of using a multi-methodology are related with the fact that real world problems traditionally are multidimensional. So, dealing with the complexity of problems using different methods, in different intervention stages, is very useful and advantageous. Additionally, even at the same intervention stage, the use of different methods can bring new insights and increase the reliability of the results.

The process can be described as follows:

- The starting point is the population health index, being this the source of information for all the analysis, since the index gives information about the values for each region in several dimensions;
- The information captured with the index is complemented with the definition of multiple objectives to be used and guide the evaluation and selection of policies, e.g. promoting population health and equity;
- Departing from the index and taking into account the objectives to be pursued, several analysis can be done in order to characterize the status quo (current state of the population according to multiple dimensions of the population health index, before any policy is implemented) of the population according to the index. This is done using clustering methods;
- Using the information on the status quo and having in mind the main objectives, a sample of policies is defined and adapted to the specific context of a population health index;
- Afterwards, a key point is the assessment of the different combinations of policies, in order to obtain the impact of implementing these different policies on the multiple dimensions of the population health index;
- Based on the previous assessment, it is possible to evaluate the different combinations of policies and find out what are the combinations of policies with the highest impact on the selected objectives, when some restrictions are considered. This evaluation is performed using mathematical programming models;
- The last point is the communication of the results, in a clear and easy way to the decision makers and key stakeholders. This last step closes the process of evaluating policies with a population health index.

To sum up, this multi-methodology is composed by 7 sequential stages, which are described on the figure 2**.** These steps are presented in detail in the following sub-sections, after the mathematical notation.

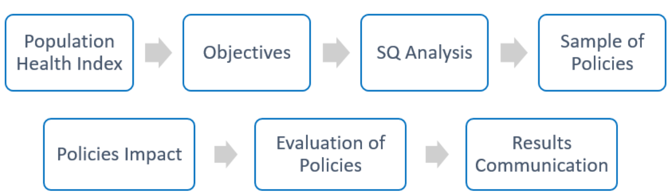

Figure 2 - Diagram representing the multi-methodology to evaluate polices with a population health index.

Additionally, a main issue was how to combine the different methods that were needed to deal with the challenges of each stage. So, the multi-methodology is the result of the combination of a group of methods that influence each other. Therefore, attention had to be given on how to guarantee that the results of one step make sense and can be of used in the following stages. However, the main limitation to the methods and its application is the population health index and its intrinsic characteristics, by limiting how the different dimensions values are presented and all the process of analysing the status quo and applying the policies. In this way affecting all the other methods that were selected to be used.

A. Notation

In this sub-section, a list of the notation used across the multi-methodology is defined:

Indices:

- i *or* h – Geographical regions. This index varies between 1 and number of regions;
- j – Different dimensions of the population health index. This index varies between 1 and number of dimensions;
- l – Portfolio of policies. This index varies between 1 and number of portfolios;
- k – Objectives. This index varies between 1 and number of objectives;

Variables:

- x_l – Type of selection of portfolio l, such that if $x_l = 1$ the portfolio l is selected, and if $x_l = 0$ the portfolio l was not selected;
- $objective\ measure_k$ – Objective measure k;
- $optimal\ value_k$ – Objective function after solving the mathematical programming model using only objective measure k;

Parameters:

- V_{ij} - Value in the region i of the dimension j of the population health index;
- $\bar{V}_j$ - Arithmetic average of the Value across all regions on dimension j of the population health index;
- Vap_{ij} - Value in the region i of the dimension j after the policies of the population health index;
- Vsq_{ij} - Value in the region i of the dimension j in the status quo of the population health index;
- P_i – Population of region i;
- $\bar{P}$ - Arithmetic average across all regions;
- w_j - Weight of dimension j;
- HG_j - Health gains on dimension j;
- N - Number of regions;
- n - Number of data points on the clustering algorithm;
- $weight_k$ – Weight attributed to the measure k;

B. Steps of the multi-methodology

1) Population Health Index

The first step of the multi-methodology is called Population Health Index, being the key source of information that will be used on the following stages of the multi-methodology. The Population Health Index characterizes the population health in different regions (e.g. Lisboa, Porto and Faro), on several dimensions (e.g. access to healthcare and mortality rates).

In this multi-methodology, the attention is centred just on the determinants part of the indexes, because the policies to improve the population health only impact the determinants' dimensions and not the outcomes directly

Additionally, depending of the situation and type of problem under analysis, there is no need for all of the index sections and dimensions to be taken into account. So, it is possible to just use a section of the index.

2) Objectives

The key objectives include the promoting of the health gains and promoting of the multiple dimensions of equity between the regions. Nevertheless, in order to operationalize these objectives, it is required a concrete definition of several metrics – these metrics will assess the impact of the different policies in term of the different objectives. Depending on the context of the analysis, different metrics can be used, since they have different characteristics.

In the context of this study, the definition of health gains includes the improvement of some selected index dimensions across the different geographical regions, without taking into account how the values are distributed throughout the regions, i.e. the method is blind if only a region is improved vs. all the regions are improved.

To obtain the measure of health gains for a single dimension, it is required to compute the difference between all the regions' values on the specific dimension after adopting the selected combination of policies (Vap_{ij}) and all the regions' values at the status quo of the index (Vsq_{ij}). So, the health gains measure is calculated using the formula:

$$Health\ gains\ in\ dimension\ j\ (HG_j) = \sum_i Vap_{ij} - Vsq_{ij} \quad [1]$$

These measures can be blind to certain inequity issues, since high values of the dimensions can dominate the measure's result. In order to overcome this issue, we should look after for equity measures [19].

Equity is central under a macro level, since it applies at the level of populations, instead of the level of single individuals. Additionally, in order to achieve an equitable distribution across regions, it is relevant to assess the geographical distribution of the values of the dimensions, after the programmes and policies are applied [27].

However, literature, under the context of population health index is scarce. So, to overcome these challenges, the approach followed was the adaption of several measures used in the context of location-allocation problems to the population health index context [19; 33], like the measures presented below:

$$\text{Min: } \min_i V_{ij} \quad [2]$$

$$\text{Range: } \max_i V_{ij} - \min_i V_{ij} \quad [3]$$

$$\text{Gini: } \sum_i \sum_h \frac{|V_{ij} - V_{hj}|}{2N^2 \bar{V}_j} \quad [4]$$

3) Status Quo Analysis

This stage is essential because, by exhaustively understanding the current characteristics of the regions under analysis, it will be possible to assess the impact of the policies and assess which are the best ones according to the objectives defined on the previous stage. Additionally, the original status of the index will serve as the point of comparison to understand the impact of the policies, which will be applied in the index's regions.

The Status Quo Analysis have two main phases:

- The first phase is to apply the different objectives measures and to analyse the index's status quo in terms of these measures' values. These values can be used as reference points for the comparison of objectives values before and after policies are applied, in order to understand the impact of each policies;
- The second phase consists is the application of clustering methods to find regions with similar patterns, with need of similar policies. This phase is relevant for the next stages of the multi-methodology, since it gives very useful information for the selection of policies that are applied in each region, i.e., the clusters of regions which will suffer the impact of same policies.

4) Defining a sample of policies

After the previous steps, it is relevant to identify a sample of policies, and this selection should be based on the evidence of their impact in health and/or equity, as well as on whether those policies are considered appropriate to improve groups of regions with similar health characteristics and in equal needs of policies. However, in the context of this study, the process of selecting those policies is not central. For defining the illustrative sample of policies, several types of policies (redistributive, proportionate universalism, etc.) should be considered.

5) Policies impact

In order to apply the sample of the policies to the population health index, it is important that it is taken into account some of the population health index characteristics. So, a key issue when determining the impact of different policies is related to its quantification into value. This quantification should follow three steps, as described below, using as an illustrative example a policy of increasing the number of doctors:

1. To start, one needs to define how many doctors will be added/removed per region;
2. Then, there is need to determine the impact of adding/removing these doctors as measured by the number of doctors per 1000 habitants (performance formula) after the implementation of the policy. It is important to mention that each dimension of the population health index has its own performance formula and the policies impacts are first applied to this;
3. Convert this performance measure (doctors per 1000 habitants) to value by recalculating the new dimension value, taking into account how the index convert each performance to value. This conversion is done using a formula adapted and defined when the population health index was constructed.

After these steps, the policy was converted to dimension's value in the context of the population health index.

After applying the policies to the population health index and obtaining the dimensions' new values, it essential to assess the impact of the sample of policies on the population health index, using the objectives measures of the second stage of the multi-methodology. By comparing the original measures' values of the status quo with the new measures' values after the policies, the impact in health and equity can be estimated. The easiest way to assess the impact is by subtracting the original value to the new value:

$$\Delta X_{impact\ of\ the\ policy} = measure\ X_{after\ the\ policy} - measure\ X_{Status\ Quo} \quad [5]$$

This equation can give rise to two types of desired results dependent of the type of measure being used. For some measures the goal is that the policies maximize $\Delta X_{impact\ of\ the\ policy}$, e.g. of the min measure where the goal is to have a more equitable regions with a higher min value. For other measures, the goal is to reduce and have negative values of the$\Delta X_{impact\ of\ the\ policy}$, example of the range measure, where the more equitable result is to have a negative results of the equation [].

6) Evaluation of policies

At this stage, since policies and their impacts have been assessed, we can now start the process of selecting and evaluating combinations of policies that have the most potential to improve health and equity values. The process of selection and evaluation of policies (or a combination of policies) is a complex task, since many different objectives are desired to be pursuit, e.g. simultaneously improving different equity measures and health gains. Additionally, many restrictions are possibly to be taken into account, e.g. limiting the number regions without improvements or that are worsen. So, a way to surpass this complexity is to use multiobjective mathematical programming models.

The fundamental characteristic of mathematical programming is that objectives and constraints of the problem under study can be formulated using mathematical relationships, such as equalities, inequalities and logical dependencies. Since the relationships are independent of the input data, we can create a generic mathematical model, which can be applied to different problems with different indexes.

The resulting multiobjective objective function considers the value of the weighted deviation functions to goals, considering several objective measures (k's), e.g. of an objective function of a multiobjective mathematical programming model:

$$MIN \sum_{k} weight_{k} \times \frac{objective\ measure_{k} - optimal\ value_{k}}{optimal\ value_{k}} \qquad [6]$$

A relevant component of the mathematical programming models are the constraints, a way to organize the constraints is in two groups: one group with more technical oriented constraints and a second group with constraints more related with the final results implications. A key constraints is the following that forces that only one portfolio is selected:

$$\sum_{l} x_{l} = 1 \qquad [7]$$

7) Results communication

Across the previous steps and the final results should be translated into several communication strategies that help to explain the outcomes and the rationale behind the decisions that have to be taken to the decision makers. These strategies should focus in ways to visualize data, such as coloured maps, spider diagrams, and coloured tables.

C. Decision makers' involvement

The multi-methodology has the objective of being used by decision makers (DM), including policy-makers, when faced with the problem of having to select which are the best policies according to specific objectives of improving the health and equity of the regions under analysis when population health index exists and can be leveraged. These DM are called to contribute and make explicit decisions along several steps of the multi-methodology: Objectives; Status quo analysis; Sample of policies and Evaluation of policies.

Also, a MACBETH approach can be used to construct the weighting coefficients, by asking decision makers for qualitative judgements of difference in attractiveness between options. The method consists in the: *"anchoring on two impact levels [...] and determining the weights indirectly by applying MACBETH to holistic semantic judgments of difference of overall attractiveness between fictitious actions defined by the anchor levels"* [34]. The best way to use the MACBETH method, is by using the M-MACBETH, a decision support system that has the approach implemented. Additionally, the software identifies inconsistent judgments and proposes ways to correct them, also the software converts qualitative judgments in the MACBETH scale (no, very weak, weak, moderate, strong, very strong and extreme) to numerical scores and weights [35].

V. MULTI-METHODOLOGY APPLICATION AND RESULTS

The goal of this section is to illustrate the applicability of the proposed multi-methodology using the GeoHealthS index of the Portuguese municipalities.

1) Population Health Index

The multi-methodology starts with a population health index, and, in this study, the case studies are based in the GeoHealthS index [1]. Meanwhile, only the primary care (PC) responsiveness dimension was used in the case studies. This dimension is related with the number of doctors and nurses in primary care units

2) Objectives

The objectives of the cases studies are the promotion of health gains and promotion of health equity in the selected dimension and between regions of the index. So, the four measures were used - health gains, min, range and Gini.

3) Status Quo Analysis

In the first phase, the selected equity measures were applied to the dimension (Min=20,08; Range=69,95 and Gini=0,15).

In the second phase, the key characteristics are a k=5 and the index's data was transformed by subtracting the base value (PC resp. average) to the regions' values, since it was defined that the base was the minimal desired goal for all regions.

The results of the algorithm are a group of 5 clusters that can be ordered from the worst-off, cluster 1, to the best-off, cluster 5, with the centroids, max and min values for each cluster presented in the figure 3. This information is very relevant in

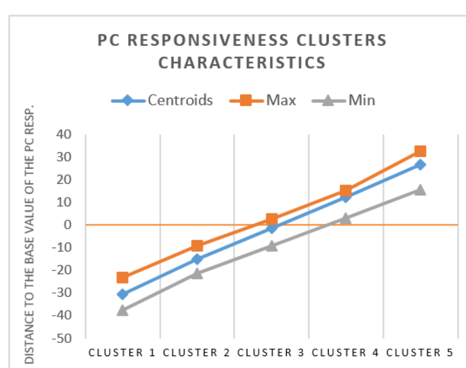

Figure 3 – Plot with the max, centroid and min for each of 5 clusters for the PC responsiveness dimension.

the sample of policies stage of the multi-methodology, since the clusters can be used in the application of policies in the index.

4) Sample of Policies

The policies used for the purpose of this study consists in adding doctors to different regions and/or redistribute them between clusters of regions of operationalization of the doctors in the regions, it was possible to define a sample of policies to be used. These sample of policies is composed by 9 different portfolios of policies:

- Plus 200 doctors in the worst-off municipalities, l=1;
- Plus 400 doctors proportional to the clusters, l=2;
- Plus 400 doctors proportional to the population, l=3;
- Plus 400 doctors distributed equally in all regions, l=4;
- Redistribution of 5% of the doctors of the two top clusters to the two worst-off clusters, l =5;
- Plus 200 doctors in the worst-off region and then redistribution of 5% of the doctors, l=6;
- Plus 400 doctors proportional to the clusters and then redistribution of 5% of the doctors , l=7;
- Plus 400 doctors in the proportional to the population and then redistribution of 5% of the doctors, l=8;
- Plus 400 doctors distributed equally in all municipalities and then redistribution of 5% of the doctors, l=9.

5) Policies impact

In this stage of the multi-methodology, the policies presented in the previous subsection and the four objective measures will be used to show the policies impact in the population health index. Table 1 summarizes the impacts ($\Delta\, X_{impact\ of\ the\ policy}$) to three of the portfolios. These portfolios were selected because they represent different types of policy application (targeting the worst-off; 'redistributive policy'; and proportionate universalism).

Additionally, for the first two measures, the goal is to maximize them, (so, the results should be in positive values and the higher the better); and for the other two it is to minimize them (so, results may be in negative values and the lower the better).

Table 1 – Policies impact of 3 examples of types of policies with four objective measures for the SQ PC responsiveness

MEASURE	PORTFOLIO 1	PORTFOLIO 2	PORTFOLIO 5
Health gains	412	975	-45
Min	5,26	19,03	2,6
Range	-5,26	-17,33	-4,46
Gini	-0,02	-0,03	-0,02

6) Evaluation of policies

In this multi-methodology stage, the evaluation of policies is performed using the constructed multiobjective mathematical programming model. Additionally, the case study was constructed using the analysis of the previous multi-methodology stages and the results were obtained from the implementation of this model in Excel.

To construct the MP model, the objective function results from the weighted sum of the multiple objectives of equity and health gains, and from the application of the portfolios of policies in the population health index. Also, it is relevant to mention that the health gains measures and min measures have to be maximize, while the range and Gini measures have to be minimize. Other important step was the definition of the constraints and parameters of the problem. For the purpose of this study, the only constraint in use is the one defining that at only one portfolio should be selected.

Several additional, constraints could have been used, e.g. forcing that all regions were improved, define a maximum number of regions worsen or define a minimum number of regions to be improved, but for sake of simplicity these were not used in this case study.

Additionally, it is relevant to solve the model for each of the objectives, by determining the optimal values of each objective function independently of the others. Then, these individual optimal values are used as the target values, and are used in the creation of new a function that measures the amount by which any given solution fails to meet that goal:, e.g. if the optimal value of a given objective is 41.07, this value is set as the goal to be achieved and the aim will be to minimize the distance to that goal, i.e., minimize $\frac{min_{\ l} - 41{,}07}{41{,}07}$.

In the table 2, we have the optimal values for each measure, representing the model being solved individually for each metric, instead of considering all the selected measures.

Table 2 – Optimal values for each measure.

MEASURE	PORTFOLIO 1
Health gains	2149
Min	41,07
Range	48,87
Gini	0,10

Then, a weight is assigned to each measure. The values used, as example, are 0,2 to equity related measures and 0,4 to the health gains (note that the sum of the weights across all objectives should be equal to 1). This allows the creation of an aggregated objective function that is the weighted deviations to the optimal. The final objective function formula is thus as follows:

$$MAX \sum_{l} x_{\ l} \ \times \left(\begin{array}{c} 0{,}4 \times \frac{health\ gain_{\ l} - 17.632}{17.632} + \ 0{,}2 \times \frac{min_{\ l} - 41{,}07}{41{,}07} - \\ 0{,}2 \times \frac{range_{\ l} - 48{,}87}{48{,}87} - \ 0{,}2 \times \frac{Gini_{\ l} - 0{,}1}{0{,}1} \end{array} \right) \qquad [7]$$

However, the process of selection of weights is a vast field of management science theory, and of how to interact with decision-makers to get their insights. Unfortunately, for lack of time and for being out of the scope of this study, interaction with decision makers was not an option, and so the weights were arbitrarily chosen so as to illustrate the applicability of the proposed multi-methodology. Still, a relevant alternative to improve the method of selecting the weights is the MACBETH method (developed below).

After this phase, it is possible to solve the problem with the objective of maximizing the new objective function. The result was the selection of the portfolio l =7 that was the plus 400 doctors proportional to the clusters and then redistribution of 5% of the doctors.

Furthermore, the MACBETH, a portfolio decision analysis method, was used to exemplify some of its key steps, while using the M-MACBETH software. The method was created to be used with decision makers, it was applied only as an example, without their contribution.

The MACBETH protocol of questioning was followed, but without decision makers for ordering the measures and to do the judgements about the swings in the MACBETH weighting matrix, using the MACBETH qualitative scale (no, very weak, weak, moderate, strong, very strong and extreme).

The results of this method are aligned with the previous example of the mathematical programming models, being the portfolio 7 the one that has the best result. Additionally, a sensitivity analysis was conducted showing for the health gains that only for weight of more than 0,7, the portfolio 7 is not selected, being for those cases the portfolio 4, policy of plus 400 doctors distributed equally in all municipalities, selected.

This method is very interesting and powerful, especially, when decision makers are used. Unfortunately, that was not possible in scope of this study.

A complementary analysis of the results is done in the next phase of the multi-methodology, the Results Communication.

7) Results communication

After following all the other steps, the results obtained should be communicated with appealing methods. As an example, it is interesting to present how the policies will change and impact the regions using maps, such as the figure 4 below, where it is possible to observe the changes in the number of doctors for municipalities of the Lisbon area for the selected portfolio. It is interesting to observe in regions that belongs to the worst cluster (dark red) have high numbers of doctors being added, such as 17 doctors in Mafra and 10 doctors in Alenquer.

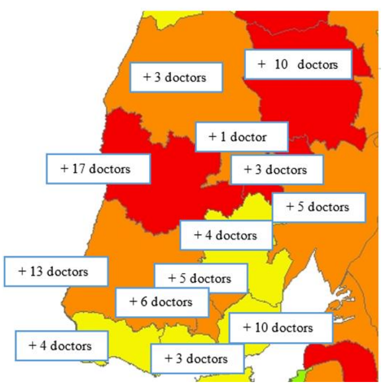

Figure 4 – Zoom in the Lisbon region of the PC responsiveness area with the additional doctors per municipality in boxes.

VI. Discussion and Conclusion

The main objective of this study was to develop methods to analyse which combinations of policies have the highest potential to promote health and health equity, using a Population Health Index. In order to achieve this goal, a multi-methodology was presented, that covered multiple aspects, from the selection and operationalization of the population health index and objectives, to the assessment of the status quo of the index using several methods, such as the clustering methods. Additionally, the multi-methodology drives the selection of policies and assesses their impact on the index, leading to the evaluation of policies using mathematical programming methods.

In the next sub-sections of this chapter, the main achievements, advantageous and disadvantageous of this multi-methodology and future work are presented.

1) Main achievements of this study

The importance of this multi-methodology comes from the fact that there is the need of reliable quantitative methods to t support decision makers in their process of evaluating which are the policies that mitigate health inequities and promote health gains, but never forgetting that the goal is to support decision makers and not to substitute them. Additionally, the work developed under this study aimed to go further than the actual state-of-the-art, by providing a set of tools for evaluation of policies based in multidimensional population health indexes. In the vast search conducted, no integral approach was found that can be used to address these challenges. Therefore, there is a need and space for a novel multi-methodology that combines a broad range of methods, such as clustering techniques and the mathematical programming models. So, the main goal of this study was to close this research gap, by designing a multi-methodology that analyses which policies have the highest potential to promote health and health equity in the context of a population health index.

In order to test the multi-methodology, data from the GeoHealthS index was used. Nevertheless, one should bear in mind that the proposed multi-methodology is generic and have potential to be used and adapted to other projects, such as the Euro-Healthy project. Also, the case studies that were presented are small subset of all possibilities that were explored and the goal with these cases was to present a combination of options that show the vast range of possibilities and approaches available to reach the end goal. Additionally, the main purpose of the application of the multi-methodology was to show, with practical examples, the full process of evaluating and selecting policies within the context of population health index, as well as illustrate the potential of this multi-methodology to be a decision support method for decision makers that have to select policies.

2) Advantageous and disadvantageous of this multi-methodology

This study used a data driven approach, leveraging on several quantitative methods. This can be interpreted as both an advantage and a disadvantage of this work, since just it only relies on quantitative data a source of information, which can sometimes be misleading and not the most insightful approach. As an example, clustering methods have the problem of being almost a black box, where the algorithm finds the solution, but many times it is hard to get meaningful insights from the results.

Additionally, during the application of the method, other weaknesses were presented other, which included the fact that it doesn't use policy makers to define the weights and instead it uses aleatory weights in the case studies.

Furthermore, during the development of this study, a key adversity had to be surpassed in the construction and testing of the multi-methodology. The adversity was the lack of a comprehensive and holistic set of policies to be evaluated. This was a key issue that was overcame using examples of policies created by the authors. Thought, no comprehensive approach was proposed to select this initial sample of policies. Nevertheless, this was a relevant and disruptive issue, interfering in the definition of a clear path of work and validation of hypothesis and methods.

Even with these weaknesses, this multi-methodology can have a space in the methods related with population health indexes, by integrating and combining different quantitative methods, such as the clustering with mathematical programming models in the context of population health indexes. Also, the multi-methodology includes the treatment of the results and its presentation with easy to interpret communication strategies (e.g. maps and tables), such as the maps of the regions. Furthermore, the analysis of the index and policies was performed taking into accounts the needs of each group of regions, by leveraging the clustering techniques, and not in a blind way, by doing the same policy to all the regions.

Furthermore, it had a practical application to a Portuguese index, the GeoHealthS. One of the main proves of the value of this multi-methodology was their presentation in the EURO 2015, the European conference of Operational Research and Management Science (ORMS), that took place in the University of Strathclyde, Glasgow. Additionally, this work was presented in the 14ª Conferência Nacional de Economia da Saúde.

3) Further work

Additionally, the methods developed in this study can inform the evaluation of policies in other projects, such as the Euro-Healthy (to improve health and health equity across European regions). Accordingly, the adaptation and further research required to the application of this multi-methodology to the Euro Healthy project is a relevant point of future work. Also, the interconnection with other streams of the project may lead to very rich insights, for example the integration of this methodology with scenario analysis or the application as a way of measuring different risks.

Moreover, a key point is the use of this multi-methodology alongside with experts and decision makers to validate and use their knowledge in the definition of several required decisions. For instance, it would be possible to use rigorous methods to infer the weights together with experts, through the use of the MACBETH approach.

At an operational perspective, the mathematical programming model should be converted from Excel to GAMS, a mainstream optimization software that is much more powerful for this purpose.

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