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Planning a long-term care network with uncertainty, strategic policy and equity considerations: A stochastic planning approach

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Planning a long-term care network with uncertainty, strategic policy and equity considerations: A stochastic planning approach

Abstract: Departing from a structuring of key uncertainties and of policy options inherent to the reorganization of a long-term care (LTC) network, this study proposes a stochastic mixed integer linear programming (MILP) model for planning the delivery of such a network. The model assists health care planners on how to plan the delivery of the entire range of LTC services – from institutional to home-based and ambulatory services – when their main policy objective is the minimization of expected costs and they consider that satisficing levels of multiple dimensions of equity need to be respected. Equity dimensions (modeled as constraints) include equity of access, equity of utilization, socioeconomic equity and geographical equity. The proposed model provides planners with key information on when and where to locate services and with which capacity, how to distribute this capacity across services and patient groups, and which changes to the network of care are needed over time (increasing and reducing capacity, and the opening and closure of services). Model outputs take into account the uncertainty surrounding LTC demand, and vary according to strategic health policy options adopted by governments. The applicability of the model is demonstrated through the resolution of a case study in the Great Lisbon region in Portugal. Results illustrate how the LTC network should evolve when different strategic health policy options are adopted, and provide estimates of the expected costs of achieving satisficing equity levels.

Keywords: LTC planning; multi-service; uncertainty; policy decisions; equity; Portugal

1. Introduction

Long-term care (LTC) includes a broad range of health and social services designed for individuals who are dependent on help with basic activities of daily living due to chronic illness and/or disability [1]. LTC differs from conventional health care since its main goal is not to cure but to promote quality of life in general [2]. Developed countries have already established LTC programs within the scope of health and welfare systems, but many developed countries are still in an early stage of developing such programs, and in some cases nothing was done so far [3]. Literature in the area shows that distinct countries differ in the way they organize and provide these services, either by 1) providing care in a variety of settings, including short-term to longer institutionalizations, home-based and ambulatory services, 2) having different divisions of responsibility in the provision of care, that can be shared between the family and the public and private sectors, 3) establishing different boundaries between the health and social care services, and 4) defining different financing schemes [4-6]. For instance, in countries based on a National Health Service (NHS) structure, such as in Portugal and countries of the UK, both health and social LTC services are delivered to the population, with access to health-related services being nearly free at the point of use and financed based on taxes [7-8]. On the other hand, social care services are not instituted to be nearly free and a universal right, with access being means-tested [7-8]. Often, the main LTC providers in these countries are private institutions.

One of the challenges that most healthcare systems across Europe are currently facing is the increasing demand for LTC [9]. This is mainly due to the ageing phenomenon, the increase in the prevalence of chronic diseases, the changes in the family structure and the increasing proportion of women in the labor market [2,9]. According to the European Policy Council [10] a 151% increase in the number of people requiring LTC in the European Union is expected between 2007 and 2060. For the particular case of Portugal, one study has estimated that public LTC expenditure is expected to increase approximately 106% until 2060 [11]. Satisfying this increasing demand requires an adequate supply of care, but most healthcare systems seem to be still ill-equipped to meet this challenge [12]. This low supply of services results in an increasing utilization of health services in the acute care sector by patients requiring LTC. In fact, these LTC patients have a lower cost when compared to the same patients using care in the acute care sector, and thus this inadequate usage of service results in inefficiencies and higher costs that could be avoided with the setup of an adequate network of LTC services [13]. These higher costs become even more problematic in the context of severe budget constraints that many European countries, such as Portugal, are currently facing. Within this setting, investing and planning LTC networks currently represents a health policy priority in many European countries. In particular, in NHS-based countries facing a strong pressure to decrease public spending in health care, this planning process should promote a cost minimization while satisfying a minimum acceptable level of demand. Furthermore, the achievement of equity objectives tends to be somewhat dealt at a secondary level, being enough to respect minimally satisfying levels. Moreover, this planning should also consider the uncertainty associated with future demand for LTC [14].

The literature in the area of health care planning shows that different methodologies exist to assist the planning of networks of health care services where some objectives and key features of these systems have been addressed [15]. Within these methodologies, mathematical programming models play a key role [16], with most of these models being deterministic in nature [17]. Deterministic models provide planners with useful information for planning, but they do not take into account the uncertainties inherent in making real-world decisions [17]. Regarding the objectives most widely used in studies applied to the health sector, equity has a key role (see the references in [18]). Nevertheless, to the best of our knowledge, most studies consider only one definition of equity while planning in the health care sector [19]. Also, few models have been proposed for planning the delivery of multiple and distinct health services, e.g., institutional and home-based services (for instance, [20-21]), being the modeling of multiple related services very important for building integrated networks of care. Furthermore, although the modeling of a planning horizon is a central feature for planning a network of care in an uncertain environment (for instance considering the timing for opening and closing services, for augmenting or reducing capacities and for reallocating existing capacity [17]), few studies in strategic and tactical health care planning contexts have used that feature. In addition, the best planning decisions may differ according to which strategic health policy options are adopted by governments, and this is relevant information to be considered when planning networks of care.

Although an adequate planning of a network of LTC services should consider all these features, very few studies have proposed methods to assist the planning of LTC services and, as shown in detail in section 2, no study comprehensively considers all these features.

This study proposes a two-stage stochastic mixed integer linear programming (MILP) model – the LTC_{2SS} model, with *2SS* standing for Two-Stage Stochastic model – to support planning of strategic and tactical decisions in a LTC sector in the context of a NHS-based country. The model considers cost and equity concerns, with the main objective being the minimization of expected cost, whereas equity considerations – namely, with equity of access, equity of utilization, socioeconomic equity and geographical equity – are modeled as constraints, in the form of satisficing equity levels that need to be respected (using the satisficing concept from Simon [22], according to which policy makers want to achieve satisficing, and not optimizing levels of equity, as explained in section 3.3). The LTC_{2SS} also considers the impact of demand uncertainty and of strategic health policy options (for instance, converting acute hospitals into LTC units [23-24]) in the planning of a LTC network. As model outputs, it informs on how to (re)organize a network of LTC services, both in terms of location selection and capacity planning, by considering its multi-service nature, which includes institutional (both short-term and long-term institutionalizations), home-based and ambulatory services. In particular, it informs planners in the LTC sector on i) where and when to locate the multiple LTC services and with which capacity, both in terms of beds and human resources, ii) how to distribute this capacity across services and patient groups, iii) which changes are needed in this network over time, including capacity increasing or reduction and the opening and closure of services, and iv) how much it costs to implement these changes when equity satisficing levels need to be respected. This is key information for LTC planners deciding on how much to spend on LTC provision, in which areas, and for which services. The proposed model is applied at the county level in the Great Lisbon region in Portugal for the 2014-2016 period.

In this way, this study contributes to the health care planning literature by: considering the specificities of the LTC sector and the multi-service nature of LTC services; building a stochastic mathematical programming model that considers the effect of uncertainty on planning decisions over an extended planning horizon; and considering the joint effect of cost and equity considerations and how different strategic health policy decisions can influence the network of care.

This article is organized as follows. A literature review on the methods used to plan the delivery of health care services is presented in Section 2. The problem under study is stated in Section 3. The mathematical formulation of the model is presented in Section 4, with the case study under analysis and key results being explored in Section 5. Some conclusions and lines for further research are included in Section 6.

2. Literature review

A vast literature exists on mathematical programming models developed for location selection and capacity planning in a wide range of areas [17]. Recent reviews on this topic have been developed by Smith et al. [25], Melo et al. [26] and Arabani and Farahani [27]. When it comes to plan the delivery of health care services, mathematical programming models have been playing a role in literature, with distinctive features being valuable in different settings [16]. In particular, one can identify: a) static models where decisions are made in predefined snapshots in time or multi-period models that include a planning horizon for scheduling decisions throughout time; b) single-objective or multi-objective models; c) models considering one single service or accounting for the multi-service nature of this sector; d) deterministic models that assume that their inputs are known with certainty or models that consider the uncertainties inherent in making real-world decisions; and e) models solved to optimality or based on heuristics to generate 'good solutions' that are not necessarily optimal. In the context of our study, particular attention should be given to multi-period and multi-service approaches that account for the effect of uncertainty on planning decisions, since these are key characteristics of the planning problem addressed in this study.

This section starts by presenting a brief review on location models accounting for the effect of uncertainty in many different areas. Afterwards, studies developed for health care planning are analyzed, along with the features that are considered relevant for planning a network of LTC services. At the end of this section, a review on planning models developed in the LTC sector is presented.

2.1. Location selection and capacity planning under uncertainty

Planning under uncertainty has been addressed by several authors in different areas of application, with a huge number of studies applied to general supply chain planning (see, for instance, the study developed by Georgiadis et al. [28]) and with several applications to specific areas, such as for petrochemical industry planning, refinery planning and water resource planning [29]. Most of existing studies aim at planning at a tactical or strategic level, but few studies exist comprehensively addressing uncertainty at these two levels [30] – an example of this is the recent work developed by Cardoso et al. [31] who developed a MILP model for designing and planning supply chains when the demand is not known with certainty.

When addressing uncertainty, sensitivity analysis is the simplest approach to be used, allowing the quantification of the effect of changing input values on the mathematical programming model outputs [17]. Nevertheless, as noted by Mulvey et al. [32] and Owen and Daskin [17], this approach represents a reactive analysis that analyzes the robustness of a solution after running the model, not incorporating uncertainty into the model in a proactive manner; and produces several model solutions according to the scenarios. So as to overcome these limitations one can resort to other types of methodologies, such as stochastic and robust approaches [29,33-34].

In stochastic optimization approaches, uncertain parameters can be described by a known probability distribution, with probabilities being assigned to each scenario, whereas robust approaches are typically employed when no information exists on the probability distribution associated with the uncertain parameters. Stochastic approaches usually attempt to minimize expected costs (see, for instance, Nickel et al. [35]), and robust approaches often aims at minimizing the worst-case performance or regret (see the review by Aissi et al. [36]). The textbooks by Birge and Louveaux [37] and Kouvelis and Yu [38] present more details on stochastic and robust models, respectively. Notwithstanding, as highlighted by Daskin and Dean [39], the minimization of the worst-case performance or regret in robust approaches is considered to be too conservative, since '*an unlikely scenario can drive the entire solution*' (p. 14). Furthermore, stochastic models represent the most common approach used to deal with uncertainty [40]. For the purpose of this study, we have chosen to explore stochastic optimization approaches based on scenario planning, as it describes well the problem under study. These approaches have the advantage of explicitly considering a set of representative scenarios in the mathematical formulation. Doing so allows identifying a solution that performs better under all scenarios, but that may not be optimal for any specific scenario.

As reviewed by Sahinidis [33], Snyder [34] and Verderame et al. [29], stochastic approaches have been widely used in many areas, such as for capacity planning and location selection (see the references in [41]). Within the literature in the area, two-stage stochastic approaches are commonly used, with decisions on the location of facilities and capacity levels being typically used as first-stage decisions whereas allocation decisions are usually defined in the second-stage (i.e., as recourse actions) [34]. As examples, Alonso-Ayuso et al. [42] proposed two-stage stochastic capacity planning models where the capacity level is used as first-stage decisions; and MirHassani et al. [41] considered both location selection and capacity levels as first-stage decisions when planning supply chain networks. These studies considered demand as one of the main sources of uncertainty. In fact, according to Peidro et al. [40] demand is the major source of uncertainty affecting general supply chain networks. These studies propose different stochastic approaches based on scenario planning. Choosing how many scenarios to include in these studies has also been a subject of debate in the literature. Most scenario-based methodologies in the area of strategic and tactical planning make use of a small number of scenarios, such as done by Tsiakis et al. [43] and Alonso-Ayuso et al. [42]. In fact, as noted by Santoso et al. [44], considering a higher number of scenarios is not widely used in this area.

The stochastic approach proposed in this article makes use of the state of the art from developing stochastic programming models in these studies, making use of some of the before-mentioned features.

2.2. Location selection and capacity planning in the health care sector context

Many different features have been considered when developing mathematical programming models for planning the delivery of health care services. For instance, in recent years a number of multi-objective approaches have been proposed, such as those developed by Cho [45], Stummer et al. [46], Mitropoulos et al. [47], Oddoye et al. [48] and Smith et al. [49]. Still, when compared to mathematical programming models relying on the use of a single objective, these are reduced in number [50]. Within the objectives most widely used in the literature in the area, equity plays a key role [45,47,49], being one the fundamental objectives when planning the delivery of health care in NHS-based systems [51-52]. In particular, different equity concepts have been proposed in the literature: equity of utilization has been proposed by Oliveira and Bevan [53]; equity of access has been used by Mehrez et al. [54] and Mestre et al. [21]; geographical equity has been used by Earnshaw et al. [55]; and the relevance of introducing a socioeconomic equity objective was highlighted by Drezner and Drezner [56]. The existence of different types of equity has also been noted by Mot el at. [57]. Nevertheless, although it is known that different definitions of equity may conflict with each other [19], up to our knowledge, no study exists addressing the joint effect of multiple equity concepts. In addition to equity, minimization of total costs has also been considered in these models [46].

The multi-service nature of health care services has also been addressed in the literature. Examples are the studies developed by Santibáñez et al. [20] and Mestre et al. [21] – the first authors proposed a model to locate different clinical services and allocate bed capacity across hospitals; and the latter developed a model to support decisions on the location and supply of hospital services, including inpatient care, emergency care and external consultations. Notwithstanding, there are still few studies addressing the joint planning of multiple and distinct services.

Considering a planning horizon divided into a set of time periods is also relevant when developing mathematical programming models (as noted by Ballou [58] and Roodman and Schwarz [59]), and a wide variety of multi-period approaches have been developed for operational planning in the health care sector (see, for instance, Cardoen et al. [60] in the area of operating room scheduling). Nevertheless, this type of models has been rarely used for strategic and tactical health care planning, and, up to our knowledge, only Santibáñez et al. [20], Ghaderi and Jabalameli [61] and Mestre [62] have developed research in this area. The effect of following different strategic health policy options and their impact on planning decisions has been recognized as relevant, but few authors have considered this issue when planning in the health care sector. Maenhout and Vanhoucke [63] is one of these few studies, having considered how different policy decisions on the hospital staffing level impact on scheduling decisions and vice-versa.

Other features have also been considered in the literature in the area of health care planning. For instance, Smith et al. [64] and Mestre et al. [21] considered the hierarchical nature of health care provision, Günes and Yaman [65] focused on the problem of hospital re-planning after hospital network mergers, and Syam and Côté [66] addressed the planning of specialized health care services provided by non-profit organizations. The location of specialized health care services have also been considered by Mahar et al. [67].

All the above studies propose mathematical programming models that are deterministic in nature, since their inputs are all assumed to be known with certainty. Nevertheless, although these deterministic approaches provide planners with useful information for location selection and capacity planning, '*they are not able to adequately model the uncertainties inherent in making real-world strategic decisions*' [17] (p. 424). Up to our knowledge, only Abdelaziz and Masmoudi [68] and Mestre [62] have considered the effect of uncertainty while planning the delivery of health care services – the first authors developed a stochastic capacity planning model to assign beds to hospital departments when the demand for care is random, whereas the latter developed stochastic mathematical programming models to deal with the uncertainty associated with demand estimates while reorganizing a network of hospital services. This shows that the literature in this area is relatively recent. In fact, when it comes to address uncertainty in health care planning, simulation approaches appears as the most widely used technique (see, for instance, Harper et al. [69]).

2.3. Location selection and capacity planning in the long-term care sector

Few methods have been proposed in the literature for supporting the planning of LTC services [70]. One of the first models developed for this purpose dates back from 1998 and aimed at proposing a single-objective mathematical programming model for analyzing whether home-based LTC can serve as a cost-effective alternative to nursing care [71]. LTC provided in home-based settings was also the focus of the study developed by Lin et al. [70], who proposed a single-objective capacity planning mathematical programming model for dimensioning the infrastructure capacity for community-based LTC services when the total spending is minimized. Capacity planning was also addressed through a simulation-optimization approach developed by Zhang et al. [72]. With respect to the location of LTC services, it was the focus of the studies developed by Cinnamon et al. [73] and Kim and Kim [74]. Shroff et al. [75] have also studied the location of LTC facilities, having proposed, to the best of our knowledge, the only multi-objective approach in this area. Furthermore, within the few studies identified in this area, and to our best knowledge, no study has addressed the multi-service nature of LTC services, the impact on planning decisions of following different policy options or the uncertain environment of this sector.

Summing up, the main features that are particularly important for this study and that are considered as relevant when planning the delivery of health care services in general, and LTC services in particular, are identified in Table 1. Note that several other characteristics can also be relevant for this sector (such as the multi-objective nature of several planning problems in the health care sector, as discussed in Chapter 3), but the intent of this table is only to review the aspects that are specifically more relevant for the purpose of the present study. Accordingly, Table 1 identifies the studies applied to the health care sector addressing one, or more, of the following features: planning under uncertainty; multiple equity concepts; multi-period; multi-service; policy options' impact; and LTC sector applications. The LTC_{MOPE} model developed in Chapter 3 is also included in this table, since several of these features have been previously addressed when building the model. Table 1 shows that no study has addressed these characteristics all together, and so the LTC_{2SS} model attempts to fill this gap in the literature.

Table 1 Analysis of health (in general) or LTC (in particular) studies taking into account a set of selected features relevant for planning

	Planning under uncertainty	**Multiple equity concepts**	**Multi-period**	**Multi-service**	**Policy options' impact**	**LTC sector applications**
Santibáñez et al. [20]			👍	👍		
Mestre et al. [21]				👍		
Oliveira and Bevan [53]		👍				
Ghaderi and Jabalameli [61]			👍			
Mestre [62]	👍		👍	👍		
Maenhout and Vanhoucke [63]			👍		👍	
Abdelaziz and Masmoudi [68]	👍					
Lin et al. [70]						👍
Greene et al. [71]						👍
Zhang et al. [72]			👍			👍
Cinnamon et al. [73]						👍
Kim and Kim [74]						👍
Shroff et al. [75]						👍
LTC_{MOPE}		👍	👍			👍
LTC_{2SS}	👍	👍	👍	👍	👍	👍

3. Problem statement

This study aims at developing a model to inform planning decisions in the LTC sector at strategic and tactical levels and in the context of NHS-based countries, while considering the impact of demand uncertainty and of different strategic health policy options. In particular, the LTC_{2SS} model – a two-stage stochastic MILP model – is developed to inform decision makers (DMs; in this study, DMs can be either an individual or a group of policy makers or health care planners with responsibilities in the LTC sector) on how to (re)organize the delivery of the entire range of LTC services (from short-term to longer institutionalizations, home-based and ambulatory services) when considering the uncertainty surrounding future demand for LTC. The model provides detailed information regarding: i) where and when to locate services and with which capacity, in terms of beds and human resources, ii) how to distribute this capacity across services and patient groups, iii) which changes regarding capacity increasing or reduction and the opening or closure of services should be carried out over time, and iv) which is the cost to implement these changes. Since different strategic health policy decisions may structurally impact the LTC sector (for instance, DMs may allow the conversion of acute hospitals into LTC units), the influence on the network of care when different health policy decisions are followed is analyzed. The model assumes that both cost and equity considerations are taken into account. While the main objective is to minimize expected costs, key equity considerations – namely, of equity of access, equity of utilization, socioeconomic equity and geographical equity – are modeled as constraints, taking the view that in a context of a strong scarcity of resources, only satisficing levels of equity need to be respected.

In this section, detailed information regarding the LTC planning problem is provided, namely: the general features of the LTC network; the planning decisions; the policy objectives; the strategic policy decisions at the health system level that should be accounted for; the key sources of uncertainty; and the mathematical programming approach selected for dealing with this problem.

3.1. Key features of the LTC network

We consider a LTC network that has a multi-service nature, with services ranging from short-term and long-term institutionalizations to home-based and ambulatory services, and that is operating in the context of a NHS-based system. Health systems based on a NHS structure are commonly characterized by universal coverage and nearly free access at the point of use, and are also characterized by a mix of public and private providers [7]. The key features of this type of LTC network are briefly described in this section. We consider a generic network, but whenever required we use features of the network currently operating in mainland Portugal as a reference so as to allow for a better understanding of how such a network operates (details on the Portuguese LTC system can be found in [7]). Note that the LTC system in Portugal is rather similar to the one operating in other European countries, such as the one in countries in the UK and Italy. A detailed description of these systems is available in [8] and [77].

The National Network of Long-Term Care (*Rede Nacional de Cuidados Continuados Integrados*, RNCCI) is operating in Portugal since 2006, and ensures the provision of both health and social care services for individuals who are dependent on others to perform their daily activities, frail elderly, highly disabled and/or severely ill, in this later case in an advanced or terminal phase [8,78-79]. For the setup of the RNCCI, the government claimed that LTC was central for ensuring the sustainability of the NHS-system and to improve the performance of the health care system, by making a better use of available resources and by adjusting the delivery of care to the real needs of the population (for instance, by replacing costly acute care by LTC services, which are typically cheaper) [24].

For the purpose of our study, only the health care component of LTC is considered. The Ministry of Health is responsible for delivering this component, and LTC provision is ensured through a wide range of institutional, home-based and ambulatory care services [23]. More specifically, the following services are provided:

- Short-term and longer institutional care (IC) services integrate the delivery of convalescence care (CC), medium-term and rehabilitation care (MTRC), long-term and maintenance care (LTMC) and palliative care (PC) for individuals with different conditions and that cannot receive care at home. The delivery of these different services is associated with different lengths of stay (LOS) and resources (both material and human). These services are also characterized by different occupancy rates, but overall occupancy is typically high, approximately 90% [24];

- Home-based care (HBC) is provided at patients' home to individuals whose conditions do not justify the admission into an IC service but cannot move and perform their daily activities on an autonomous basis;
- Ambulatory care (AC) is provided to patients whose conditions do not justify the provision of IC or HBC.

IC services are mainly provided by private not-for-profit institutions with a charitable background and other non-governmental organizations, with the state having a very limited role as IC provider [7]. In fact, the state is mainly responsible for celebrating contracts with providers and for providing the funds required for ensuring the delivery of LTC, with this funding being based on the effective utilization of services [80]. Regarding the provision of HBC, the state has a much more active role, since HBC is provided by teams of professionals created within the scope of the primary health care sector, namely, within each primary health care center (PHCC) [81-82]. In fact, according to Portuguese legislation, all the existing PHCCs should have teams of professionals able to ensure the provision of HBC [83]. Additionally, although defined as one of the typologies of LTC services, AC is not yet provided on a formal basis in Portugal, mainly due to budget constraints and also due to the lack of specific legislation defining how these services should operate [82]. Prior to being accepted in one of these LTC services, the eligibility of individuals in need is evaluated in an NHS hospital (whenever individuals are already receiving care in a NHS hospital) or in a primary care provider (whenever individuals are at home or in a private institution) [78]. Once evaluated, individuals are allocated to the most adequate service (according to their health condition) and to the closest available service in their area of residence. Note that for the particular case of HBC the closest available service is the PHCC belonging to the place of residence of each individual in need. Furthermore, for the particular case of IC services, if no bed is available in any geographical area, individuals will stay on a waiting list [4]. The provision of all these types of LTC services is ensured by teams of health professionals that comprise, among others, physicians and nurses, with these teams differing according to services [82].

Available evidence points out that, although already in place, the current network of LTC services is still far from meeting the current needs for LTC [14]. Moreover, Lisbon and Tagus Valley is the Portuguese health region with the lowest relative supply of LTC services [84].

3.2. Planning decisions

The planning decisions considered are as follows:

- Where and when to locate new services? New IC services can be located in existing locations or in new locations where no IC provision exists. In the general context of a NHS-based system, locating an IC service implies that the state should create conditions for providing that care on that location, either through state provision or by contracting non-governmental providers. Differently, the location of HBC and AC services is not modeled in this study – for instance, HBC is provided by teams of professionals from PHCCs, and the network of primary health care services is well established in most European NHS-based countries [7,85]. Within this setting, all the structures that are needed for ensuring the provision of HBC are already in place. Without related information about the provision of AC, for the purpose of this study, we assume that AC services should be delivered similarly to HBC services, and so there is no need to physically install new structures for both HBC and AC provision (one should however note that, although the location of these services is not modeled in this study, the dimensioning of their capacity is considered, as described below in this section);

- How many beds should be installed in each IC service in each time period? And which is the additional bed capacity in which to invest over time to achieve this bed capacity? Departing from an existing network of services, the beds initially installed in the network should also be used for IC provision, and so there is a need to distinguish between total and new bed capacity;
- How many human resources, in terms of hours of care provided by different types of health professionals, are needed for providing IC, HBC and AC over time? And how many additional hours of care need to be contracted for each service and location each year? The volume of hours of care that are currently provided in the existing network of LTC should also be accounted for planning;
- How to (re)distribute resources across services and patient groups over time? Since LTC demand is known to evolve over time [14], a transfer (or reallocation) of beds is allowed across different services and/or locations, thus allowing for adjustments in the supply of care and avoiding the loss of previous investments made in the network. The transfer of human resources is not considered, but increasing and reducing the number of hours of care contracted in each service is allowed. The distribution of services across patients groups is also relevant because different groups might need to be treated differently.

3.3. Policy objectives

Planning decisions need to consider the policy objectives relevant for any NHS-based system in general, and for the LTC in particular. According to policy statements and literature in the area, key policy objectives include [7,51,86]: a) ensuring a complete coverage of LTC demand, with access nearly free at the point of use; b) promoting equality of access to health care for the citizens, regardless of their economic condition and geographical distribution; and c) promoting equity in the distribution of resources and use of health care services, and also across groups with different socioeconomic characteristics and from distinct geographical areas.

Nevertheless, in the current context of severe budget cuts that most European countries are facing (where Portugal is included), it may not be possible to satisfy all the demand for LTC. In such a context, there is a very high pressure to minimize costs when (re)organizing a network of LTC services while ensuring that a minimum level of demand is satisfied, with the achievement of equity objectives not being a first priority.

Therefore, for the purpose of this study, we consider that DMs with planning responsibilities in the LTC sector want to minimize costs while ensuring the achievement of minimum acceptable levels for different types of equity. We use here the satisficing concept from Simon [22], in that policy makers want to minimize costs while satisficing, and not optimizing, levels of equity, with equity being defined in the following dimensions (depending on the context, more equity dimensions can be eventually considered):

- Equity of access: the total travel time to access services should not exceed a pre-defined maximum value (according to DMs' point of view), thus ensuring that individuals requiring LTC will receive the care they need not far away from their place of residence;
- Equity of utilization: the level of unmet need for the group of individuals requiring the type of service with the lowest (relative) provision should not exceed a pre-defined maximum value (according to DMs' point of view). Modeling this ensures that the demand for different types of services is more equally considered and avoids situations in which individuals requiring certain services do not receive the care they need (for example, individuals with longer LOS);
- Socioeconomic equity: the level of unmet need for the population groups with lower income should not exceed a pre-defined maximum value (according to DMs' point of view), with the aim of avoiding situations of poverty or financial dependency;
- Geographical equity: the level of unmet need for the geographical area with the highest level of unmet need should not exceed a pre-defined maximum value, thus ensuring a minimum level of service (according to DMs' point of view) in the worst-off areas.

3.4. Structuring policy decisions

Different strategic policy decisions at the health system level may have substantial impacts on the LTC sector. We thus consider relevant to structure key decisions and to analyze their impact in the organization of the LTC network.

Strategically, the Portuguese government has recognized the relevance of [23-24]: 1) converting acute hospitals into LTC units; 2) transferring resources (human [HR], material [MR] and financial [FR] resources) from the acute care sector to the LTC sector; and 3) changing paradigm of the LTC provision, for instance, towards a community-oriented paradigm (i.e., transferring part of individuals needing IC to receive HBC as a substitute service, and with these individuals living in the community). Hence, different combinations of these strategic decisions should be analyzed. Using a strategy generation table as designed by Kirkwood [87], six relevant combinations can be identified – denoted by policy strategy (PS) I, II, III, IV, V and VI –, as depicted by the different symbols in Fig. 1. As an example, Fig. 1 should be read as follows: PS I results from combining all the strategic decisions assigned with a circle, which are 1) converting an acute hospital into a LTC unit, 2) transferring resources from the acute care to the LTC sector, and 3) following a community-based paradigm. This tool is particularly useful to find which combinations can occur and make sense, after excluding policy combinations that may make no sense. For instance, referring to the strategy generation table shown in Fig. 1, if DMs in the LTC sector consider converting a given acute hospital into a LTC unit, this decision only makes sense if there is a transfer of acute care resources for the LTC sector (for instance, material resources). For this reason, one should not analyze a policy strategy that allows a hospital conversion without enabling the transfer of resources from the acute care to the LTC sector.

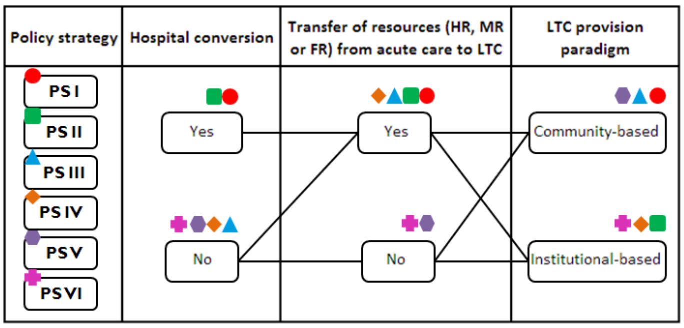

Fig. 1 Strategy generation table built for identifying policy strategies (PS). Legend: PS – policy strategy; HR – human resources; MR – material resources; FR – financial resources

3.5. Structuring uncertainty

Future LTC demand depends on several factors, such as on changes in epidemiological and demographic profiles, which are difficult to foresee with confidence [88]. It also depends on the availability of informal care, being this availability also difficult to anticipate due to changes in the employment rates of women (the most common informal caregiver) and due to the co-residence of older and disabled people with their children [89]. As a result, a high level of uncertainty is associated with expected variations in future predictions of LTC demand, as shown in Chapter 2 [14]. For this reason, it is central to plan the delivery of LTC taking into account different types of uncertainty, such as regarding the model's structure or input data [90]. In this study, only data uncertainty associated with future LTC demand is considered, with two sources of uncertainty being accounted for: a) on the number of individuals requiring LTC over time; and b) on the amount of services required by those individuals, as captured by the LOS. Note that this later uncertain component is not strictly a demand parameter, being also influenced by supply factors.

In this study, we consider that the probability distributions associated to each of the above uncertain parameters are known and a scenario tree approach [37,91] is selected for handling the uncertainty associated with that data, in the context of developing a stochastic programming model. Briefly, a scenario tree is composed by a set of nodes and arcs (see Fig. 2) [91]. Each node represents a possible realization of the uncertain parameters at a given stage, and each arc denotes the evolution between nodes from one stage to another; and a probability is associated with each arc and node, where the probability of each node in the scenario tree is calculated as the product of probabilities of the arcs from the root node up to the considered node. In this type of scenario trees, each scenario consists on the path from the root node to a leaf node. For the purpose of this study, we consider that the planning horizon consists of a fixed number of time periods where these correspond to the decision points, and so each stage correspond to a time period (note that each stage does not necessarily include one single time period).

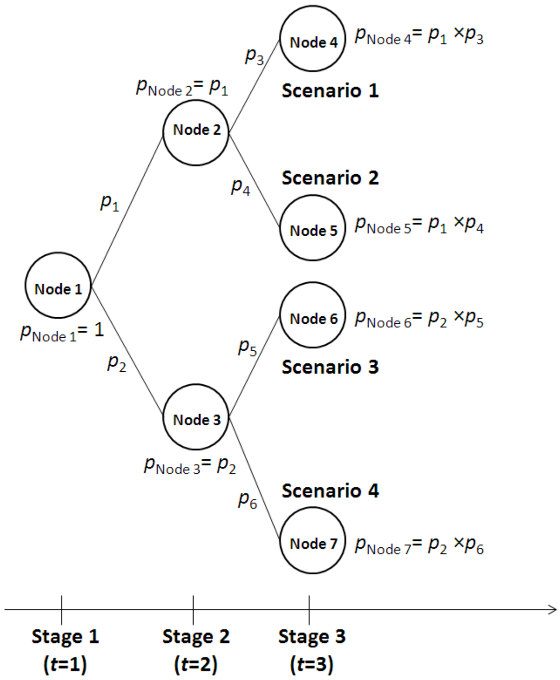

Fig. 2 Standard scenario tree

3.6. Selected stochastic programming approach

Within the group of mathematical programming methods based on scenario planning, a stochastic MILP model is used. In particular, a two-stage stochastic approach is selected, and so there is a need to define which are the first-stage decisions (i.e., decisions that need to be taken before uncertainty is disclosed) and which are the second-stage decisions, also known as corrective decisions that are taken with full information on the uncertain parameters [37]. In the literature it is common to find location decisions defined in the first-stage, whereas allocation decisions are usually defined as recourse actions (i.e., defined as second-stage decisions) [34]. We follow this direction: first-stage decisions comprise the opening and closure of services (i.e., location decisions), and second-stage decisions include decisions on the allocation and reallocation of resources and individuals in need. For the particular case of this study, and given that the definition of these first-stage and second-stage decisions should also depend on the context under analysis [37], first-stage decisions also include decisions related to the investment in new beds. Investment decisions have also been defined as first-stage decision by Nickel et al. [35], although in the context of a general supply chain network. The opening and closure of services and the investment in new beds imply building new structures or expanding and adapting existing ones, thus representing decisions that need to be taken before the uncertainty is disclosed –

in fact, these decisions take time to implement, involve significant investments and need to remain valid for longer periods of time [23,92].

The objective of the LTC_{2SS} model is to minimize total expected cost over the uncertain demand scenarios, while ensuring that a minimum level of demand is satisfied, and with the attainment of the satisficing levels of equity, above described, being modeled through a set of constraints. Two types of costs are minimized in the objective function:

- Operational costs – include costs associated with the operation of beds installed for IC provision, and with the provision of HBC and AC;
- Investment costs – include costs associated with the investment in new beds for IC provision and with the reallocation of beds between different services and locations.

Note that, on the one hand, the operational costs associated with IC provision represent the amount paid to both governmental and non-governmental providers so that they ensure the operation of IC services in line with the contractual agreements established with the state (be aware that questions regarding to which providers to contract and how each provider should organize its own delivery of care are outside the scope of our study). On the other hand, operational costs related to HBC and AC provision represent the amount that should be made available for health professionals from each PHCC providing the needed care. Further it is important to note that the costs associated with investments in new beds represent the amount paid by the state to increase bed capacity in both governmental and non-governmental structures. Nonetheless, depending on the health system under study, reallocation costs may eventually not apply – for example, in countries where the state only finances the effective delivery of IC services, these reallocation costs may not be explicitly paid but may integrate normal prices.

Based on the features above described, Fig. 3 shows how the proposed LTC_{2SS} model should plan changes to an existing network of LTC services while minimizing expected costs. The model considers the impact of the uncertainty surrounding LTC demand and of different strategic health policy options, and also uses information on the satisficing levels of equity. Fig. 3 should be read as follows – departing from an initial network of care, one should consider:

i) Closing existing services, such as the CC service initially provided in one of the units;

ii) Opening new services, such as happens with the CC service that starts operating in the other unit;

iii) Assigning patients to the required service (depicted through solid and dashed arrows; solid arrows represent patients receiving the required care in the associated service [for both IC and AC], whereas dashed arrows capture patients receiving the care they need at home [for HBC]);

iv) Computing how many beds and human resources are needed per service;

v) Reallocating beds across services and locations (depicted through dotted arrows).

All these decisions are evaluated over time and should respect a set of model restrictions. Particularly, individuals from each demand point should be assigned to a single service and to the closest available service within a maximum travel time (for IC) (and this is captured by the dotted circles in Fig. 3) or to the primary care provider belonging to their place of residence (for HBC and AC). Furthermore, services cannot be opened/closed after being closed/opened in the past, and maximum and minimum capacities should be respected.

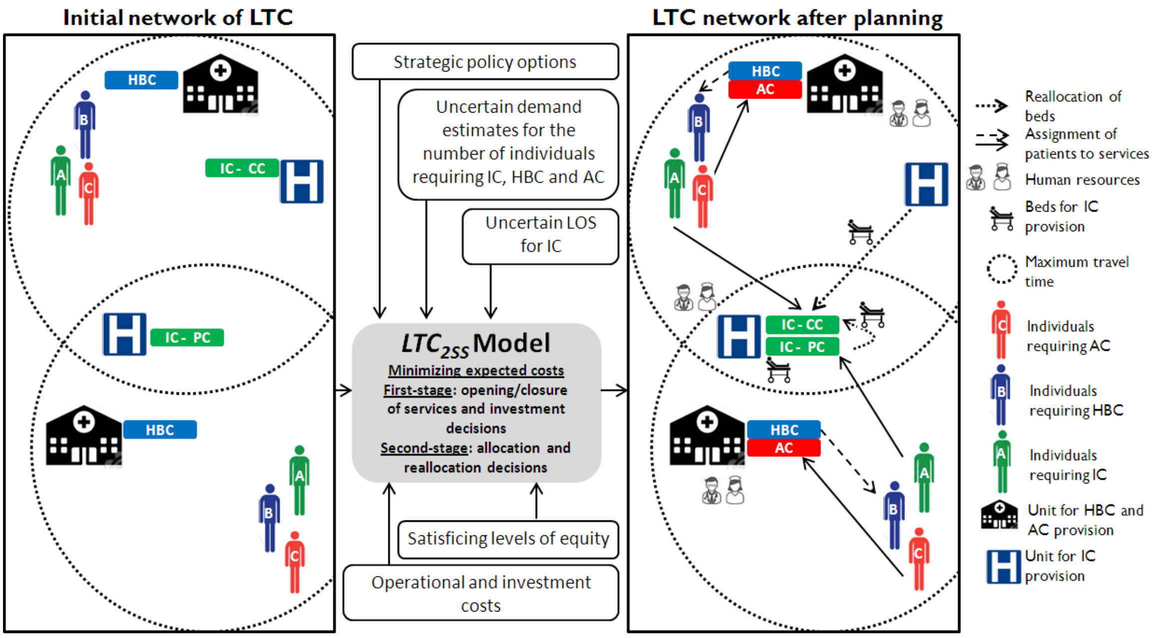

Fig. 3 Representation of how the LTC_{2SS} model plan changes an existing network of care. Legend: IC – institutional care; HBC – home-based care; AC – ambulatory care; CC – convalescence care; PC – palliative care

4. Building the LTC_{2SS} model

The mathematical details of the LTC_{2SS} model are presented in this section. We start by introducing the notation used for the model formulation, and a description of the objective function and constraints follow.

4.1. Notation

4.1.1. Indices

d	Demand points
g	Socioeconomic groups
$l,\ j$	Locations for services
r	Human resources
$s\ ,p$	LTC services
$t\ ,w$	Time periods
$n\ ,k$	Scenario tree nodes

4.1.2. Sets

D	Set of demand points
R	Set of human resources
T	Set of time periods
N	Set of scenario tree nodes
$G = G_P \cup G_{NP}$	Set of socioeconomic groups, divided into subsets G_P and G_{NP} – G_P represents the subset of groups of individuals with priority as a result of having lower levels of income, $g \in G_P \subseteq G$; and G_{NP} represents the subset of groups of individuals that have no priority as a result of having higher levels of income, $g \in G_{NP} \subseteq G$.
$L = L_I \cup L_O$	Set of locations for services, which is divided into subsets L_I and L_O – L_I represents the subset of locations for IC services, $l,j \in L_I \subseteq L$; and L_O represents the subset of locations for HBC and AC services, $l,j \in L_O \subseteq L$
$S = S_I \cup S_O$	Set of LTC services, which is divided into subsets S_I and S_O – S_I represents the subset of IC services, $s,p \in S_I \subseteq S$; and S_O represents the subset for HBC and AC services, $s,p \in S_O \subseteq S$
$A = \{(s,r): s \in S, r \in R\}$	Set of human resources r required to provide each LTC service s
$F = \{(d,l): d \in D, l \in L\}$	Set of locations l where individuals from demand point d can receive LTC
$P = \{(n,k): n,k \in N\}$	Set of predecessors k of the scenario tree node n
$Q = \{(t,n): t \in T, n \in N\}$	Set of scenario tree nodes n that belong to each time period t
$U = \{(s,l): s \in S, l \in L\}$	Set of locations l where each LTC service s can be provided
$V = \{(s,l): s \in S, l \in L\}$	Set of services s provided in locations l at the beginning of the planning horizon
$Z = \{(s,l): s \in S, l \in L\}$	Set of services s not provided in locations l at the beginning of the planning horizon

4.1.3. Parameters

D_{dgstn}	Number of individuals from demand point d and socioeconomic group g requiring service s at t in scenario tree node n
gD_{tn}	Number of individuals belonging to the lower income groups ($g \in G_P \subseteq G$) requiring LTC at t in scenario tree node n
rD_{dtn}	Number of individuals from demand point d requiring LTC at t in scenario tree node n
uD_{stn}	Number of individuals requiring service s at t in scenario tree node n
eB_{sl}^{0}	Number of beds available in IC service s ($s \in S_I \subseteq S$) located in l ($l \in L_I \subseteq L$) at the beginning of the planning horizon
mB_s	Minimum bed capacity allowed for IC service s ($s \in S_I \subseteq S$)
MB_s	Maximum bed capacity allowed for IC service s ($s \in S_I \subseteq S$)

eHR^0_{rsl}	Number of hours of care provided by human resource *r* in service *s* located in *l* at the beginning of the planning horizon
HRp_{rs}	Hours of care that should be provided by human resource *r* for each individual requiring service *s*
t_{dl}	Travel time between demand point *d* and service location *l* (in minutes)
mT	Maximum travel time allowed for LTC patients accessing institutional services (in minutes)
mD_{st}	Minimum level of demand that need to be satisfied per service *s* at *t*
EA_t	Target defined for equity of access at *t*
EU_t	Target defined for equity of utilization of services at *t*
GE_t	Target defined for geographical equity at *t*
SE_t	Target defined for socioeconomic equity at *t*
iC_{st}	Investment cost per new bed installed in IC service *s* ($s \in S_I \subseteq S$) at *t*
oC_{st}	Operational cost per service *s* per period *t*
rC^1_{st}	Cost of reallocating a bed to IC service *s* ($s \in S_I \subseteq S$) from a service delivered in a different location at *t*
rC^2_{st}	Cost of reallocating a bed to IC service *s* ($s \in S_I \subseteq S$) from another service delivered in the same location at *t*
r_t	Inflation rate at *t*
LOS_{sn}	Average length of stay (LOS, in days) in IC service *s* ($s \in S_I \subseteq S$) in scenario tree node *n*
M	High value auxiliary coefficient
TP	Number of days of each time period in the planning horizon in analysis
ε_s	Efficiency factor associated with the provision of service *s*
ρ_n	Probability of scenario tree node *n*

4.1.4. Variables

First-stage variables

X_{slt}	Equal to 1 if service *s* is located in *l* at *t*; 0 otherwise
aB_{slt}	Number of additional beds to invest in for IC service *s* ($s \in S_I \subseteq S$) located in *l* ($l \in L_I \subseteq L$) at *t*

Second-stage variables

B_{dgsltn}	Number of beds to be made available for individuals from demand point *d* belonging to socioeconomic group *g* and receiving IC service *s* ($s \in S_I \subseteq S$) located in *l* ($l \in L_I \subseteq L$) at *t* in scenario tree node *n*

rB^{in}_{slpjtn}	Number of beds reallocated to IC service s ($s \in S_I \subseteq S$) located in l ($l \in L_I \subseteq L$) from IC service p ($p \in S_I \subseteq S$) located in j ($j \in L_I \subseteq L$) at t in scenario tree node n
rB^{out}_{slpjtn}	Number of beds reallocated from IC service s ($s \in S_I \subseteq S$) located in l ($l \in L_I \subseteq L$) to IC service p ($p \in S_I \subseteq S$) located in j ($j \in L_I \subseteq L$) at t in scenario tree node n
gR_{tn}	Number of individuals belonging to the lower income groups ($g \in G_P \subseteq G$) receiving LTC at t in scenario tree node n
R_{dgsltn}	Proportion of individuals from demand point d and socioeconomic group g receiving service s in location l at t in scenario tree node n
rR_{dtn}	Number of individuals from demand point d receiving LTC at t in scenario tree node n
uR_{stn}	Number of individuals receiving service s at t in scenario tree node n
aHR_{rsltn}	Number of additional hours of care that need to be provided by human resource r in service s located in l at t in scenario tree node n
eHR_{rsltn}	Number of hours of care provided by human resource r that are no longer required in service s located in l at t in scenario tree node n
$HR_{rdgsltn}$	Number of hours of care provided by human resource r for individuals from demand point d belonging to socioeconomic group g and receiving service s located in l at t in scenario tree node n
t^{tot}_{tn}	Total travel time (in minutes) at t for scenario tree node n
t^{pen}_{tn}	Penalty (in minutes) attributed to individuals not receiving institutional care at t in scenario tree node n
$t^{\max}_{tn}$	Maximum total travel time (in minutes) at t in scenario tree node n
TIC_{tn}	Total investment cost at t for scenario tree node n
TOC_{tn}	Total operational cost at t for scenario tree node n
α_{sltn}	Equal to 1 if at least one bed is reallocated to IC service s ($s \in S_I \subseteq S$) located in l ($l \in L_I \subseteq L$) at t in scenario tree node n; 0 otherwise
γ_{slt}	Equal to 1 if there is need to invest in new beds for IC service s ($s \in S_I \subseteq S$) located in l ($l \in L_I \subseteq L$) at t; 0 otherwise

4.2. Objective function

$$Min \sum_{n \in N} \sum_{t:(t,n) \in Q} \rho_n \left(TIC_{tn} + TOC_{tn} \right) \tag{1}$$

$$TIC_{tn} = \sum_{s \in S_I} \sum_{\substack{l \in L_I \\ l:(s,l) \in U}} \left(aB_{slt} \frac{iC_{st}}{(1+r_t)^t} + \sum_{p \in S_I} \sum_{\substack{j \in L_I \\ j:(p,j) \in U \\ j \neq l}} rB^{in}_{slpjtn} \frac{rC^1_{st}}{(1+r_t)^t} + \sum_{\substack{p \in S_I \\ p:(p,l) \in U}} rB^{in}_{slpltn} \frac{rC^2_{st}}{(1+r_t)^t} \right) \forall (t,n) \in Q \quad (2)$$

$$TOC_{tn} = \sum_{d \in D} \sum_{g \in G} \left(\sum_{s \in S_I} \sum_{\substack{l \in L_I \\ l:(s,l) \in U \\ l:(d,l) \in F}} B_{dgsltn} \frac{oC_{st}}{(1+r_t)^t} + \sum_{s \in S_O} \sum_{\substack{l \in L_O \\ l:(s,l) \in U \\ l:(d,l) \in F}} R_{dgsltn} D_{dgstn} \frac{oC_{st}}{(1+r_t)^t} \right) \forall (t,n) \in Q \quad (3)$$

Eq. (1) presents the model objective function, which minimizes the expected cost associated with the LTC network for the entire planning period. These costs include both investment (Eq. (2)) and operational costs (Eq. (3)). Investment costs comprise costs related to the investment in new beds (first term in Eq. (2)) and to the reallocation of beds between services in different locations (second term in Eq. (2)) and in the same location (third term in Eq. (2)). Operational costs include costs associated to the operation of beds in IC services (first term in Eq. (3)) and to the provision of HBC and AC services (second term in Eq. (3)).

4.3. Model constraints

Several constraints are defined within groups that are described in this section, namely: 1) opening and closure of institutional services; 2) assignment of patients; 3) single and closest assignment; 4) demand satisfaction; 5) resources requirements; 6) capacity; 7) resources reallocation; and 8) satisficing equity constraints.

Opening and closure of institutional services: The opening and closure of IC services is defined through Eqs. (4-5). These conditions state that opening/closing an IC service is not allowed after deciding upon closing/opening it in a previous time period, respectively.

$$X_{slw} \leq X_{slt} \ \forall s \in S_I, l \in L_I : (s,l) \in (U \cap V), (t,w) \in T, w > t \quad (4)$$

$$X_{slw} \geq X_{slt} \ \forall s \in S_I, l \in L_I : (s,l) \in (U \cap Z), (t,w) \in T, w > t \quad (5)$$

Concerning HBC and AC, these are provided within the scope of a primary care network (as noted in section 3). Accordingly, since all the populations have a PHCC in their area of residence, no openings or closures are considered for these services (Eq. (6)).

$$X_{slt} = 1 \forall s \in S_O, l \in L_O : (s,l) \in U, t \in T \quad (6)$$

Assignment of patients: Eq. (7) states that individuals will only receive service *s* in locations where the required services are available.

$$R_{dgsltn} \le X_{slt} \quad \forall g \in G, (d,l) \in F, (s,l) \in U, (t,n) \in Q \tag{7}$$

Single and closest assignment: A set of constraints is used to ensure that individuals in each demand point *d* will receive IC in a single location, being this the location of the closest available service (Eqs. (8-9)). This is assumed since we are considering a NHS-based system in which services should be provided as close as possible to where need is located [7,93]. According to Eq. (8), if location *l* provides IC service *s* and is closer to demand point *d* than other location *j*, it means that patients from *d* should not receive the required care at *j*. And Eq. (9) ensures that patients cannot receive IC in locations that are not within a maximum travel time (*mT*).

$$X_{slt} + R_{dgsjtn} \le 1 \quad \forall g \in G, s \in S_I, (l,j) \in L_I : (s,l) \in U, (s,j) \in U, (d,l) \in F, (t,n) \in Q, t_{dl} < t_{dj}, l \ne j \tag{8}$$

$$R_{dgsltn} = 0 \quad \forall g \in G, s \in S_I, l \in L_I : (s,l) \in U, (d,l) \in F, (t,n) \in Q, t_{dl} > mT \tag{9}$$

Similar conditions are not defined for the remaining services (HBC and AC), since these services should be provided in the PHCC belonging to the place of residence of individuals.

Demand satisfaction: Eqs. (10-11) ensure that a minimum level of satisfied demand (captured by the parameter mD_{st}) per service *s* should be reached per time period *t*.

$$\sum_{n:(t,n) \in Q} \rho_n \left(\frac{uR_{stn}}{uD_{stn}} \right) \ge mD_{st} \quad \forall s \in S, t \in T \tag{10}$$

$$uR_{stn} = \sum_{d \in D} \sum_{g \in G} \sum_{\substack{l:(s,l) \in U \\ l:(d,l) \in F}} R_{dgsltn} D_{dgstn} \quad \forall s \in S, (t,n) \in Q \tag{11}$$

Resources requirement: Eq. (12) calculates the number of beds that should be made available at *t* for IC service *s* located in *l* for individuals from demand point *d* and socioeconomic group *g* for scenario tree node *n*. Nevertheless, since the decision related with the investment in new beds is a first-stage decision, the number of beds installed for IC provision in each service and location and for each scenario may be higher than required (since the demand varies across scenarios). Eq. (13) deals with this situation, stating that the total bed capacity that needs to be in place in each service and location cannot be less than the bed capacity required in each scenario (approach also followed by Birge and Louveaux [37]). This is achieved by imposing that the number of beds in which there is a need to invest for each IC service *s* located in *l* at *t* should be equal to the maximum difference found between the bed capacity required for that service and location at *t* (first term) and the capacity required (or installed) at *t-1* (second term) and the number of beds reallocated at *t* (third term).

$$B_{dgsltn} = \frac{LOS_{sn}}{TP} R_{dgsltn} D_{dgstn} \frac{1}{\varepsilon_s} \quad \forall g \in G, s \in S_I, l \in L_I : (s,l) \in U, (d,l) \in F, (t,n) \in Q \qquad (12)$$

$$aB_{slt} \geq \begin{cases} \sum_{d \in D} \sum_{g \in G} B_{dgsltn} - eB^0_{sl} - \left[\sum_{p \in S_I} \sum_{\substack{j \in L_I \\ j:(p,j) \in U}} \left(rB^{in}_{slpjtn} - rB^{out}_{slpjtn} \right) \right] & \forall s \in S_I, l \in L_I ; (s,l) \in U, (t,n) \in Q, t=1 \\ \sum_{d:(d,l) \in F} \sum_{g \in G} \left(B_{dgsltn} - \sum_{k:(n,k) \in P} B_{dgsl\,(t-1)k} \right) - \sum_{p \in S_I} \sum_{\substack{j \in L_I \\ j:(p,j) \in U}} \left(rB^{in}_{slpjtn} - rB^{out}_{slpjtn} \right) & \forall s \in S_I, l \in L_I : (s,l) \in U, (t,n) \in Q, t>1 \end{cases} \qquad (13)$$

Eq. (14) is used for determining the number of hours of care that should be provided by each type of human resource *r*. Eq. (15) establishes a balance between the hours of care provided by existing human resources (first term), additional hours of care that need to be provided (second term) and hours of care that are no longer required (third term) in service *s* located in *l* at *t* for scenario tree node *n* and for each type of human resource *r*. One should note that, as opposed to the conditions presented before when defining the requirements of beds within the LTC system, reallocation of human resources between services and locations is not modeled. While the reallocation of beds might result in additional costs, with costs varying depending on how the reallocation takes place (between different locations or between services provided in the same location), when it comes to consider the reallocation of human resources, we consider that there are no associated costs.

$$HR_{rdgsltn} = R_{dgsltn} D_{dgstn} HRp_{rs} \frac{1}{\varepsilon_s} \quad \forall g \in G, (d,l) \in F, (s,l) \in U, (s,r) \in A, (t,n) \in Q \qquad (14)$$

$$\sum_{d:(d,l) \in F} \sum_{g \in G} HR_{rdgsltn} = \begin{cases} eHR^0_{rsl} + aHR_{rsltn} - eHR_{rsltn} & \forall (s,l) \in U, (s,r) \in A, (t,n) \in Q, t=1 \\ \sum_{d:(d,l) \in F} \sum_{g \in G} \sum_{k:(n,k) \in P} HR_{rdgsl\,(t-1)k} + aHR_{rsltn} - eHR_{rsltn} & \forall (s,l) \in U, (s,r) \in A, (t,n) \in Q, t>1 \end{cases} \qquad (15)$$

Note that, since in health it is not expected full occupancy of services, we include an efficiency factor (ε_s) in Eqs. (12) and (14). This efficiency factor takes the value of 1 if it is expected that occupancy rates should be 100%, and it takes lower values for lower occupancy rates. This factor is also useful to distinguish between cases where contracts established with providers are based on the utilization of services or in installed capacity, assuming the value 1 in the former situation.

Capacity: Minimum and maximum capacity constraints are imposed for IC services through Eq. (16). No capacity constraints are imposed for HBC and AC services. These services are assumed to be provided within each PHCC, depending only on the existence of human resources, for which no maximum or minimum capacity needs to be applied. The hours of care contracted to provide these services will only depend on the available budget.

$$mB_s X_{slt} \leq \sum_{d:(d,l)\in F} \sum_{g\in G} B_{dgsltn} \leq MB_s X_{slt} \quad \forall s\in S_I, l\in L_I : (s,l)\in U, (t,n)\in Q \tag{16}$$

Resources reallocation: The reallocation of beds within the network of IC services should follow a set of conditions that are translated into Eqs. (17-20). Eq. (17) ensures that the number of beds reallocated to service *s* located in *l* from service *p* located in *j* should be equal to the number of beds removed from service *p* located in *j* to service *s* located in *l* (and this for each scenario tree node *n*). The maximum number of beds allowed to be reallocated from and to service *s* located in *l* at *t* for scenario tree node *n* is defined through Eqs. (18-19). Eq. (20) states that reallocating beds between services provided in different locations is only allowed in the first time period (note that reallocating beds across services in the same location is always allowed). This is essential to cope with an initial distribution of services that may be far from the optimal one.

$$rB^{in}_{slpjtn} = rB^{out}_{pjsltn} \quad \forall (s,p)\in S_I, (l,j)\in L_I : (s,l)\in U, (p,j)\in U, (t,n)\in Q \tag{17}$$

$$\sum_{p\in S_I} \sum_{\substack{j\in L_I \\ j:(p,j)\in U}} rB^{out}_{slpjtn} \leq \begin{cases} eB^0_{sl} & \forall s\in S_I, l\in L_I : (s,l)\in U, (t,n)\in Q, t=1 \\ \sum\limits_{d:(d,l)\in F} \sum\limits_{g\in G} \sum\limits_{k:(n,k)\in P} B_{dgsl(t-1)k} & \forall s\in S_I, l\in L_I : (s,l)\in U, (t,n)\in Q, t>1 \end{cases} \tag{18}$$

$$\sum_{p\in S_I} \sum_{\substack{j\in L_I \\ j:(p,j)\in U}} rB^{in}_{slpjtn} \leq \sum_{d:(d,l)\in F} \sum_{g\in G} B_{dgsltn} \quad \forall s\in S_I, l\in L_I : (s,l)\in U, (t,n)\in Q \tag{19}$$

$$rB^{in}_{slpjtn} = 0 \quad \forall (s,p)\in S_I, (l,j)\in L_I : (s,l)\in U, (p,j)\in U, (t,n)\in Q, l\neq j, t>1 \tag{20}$$

Under certain circumstances, an additional set of reallocation conditions can be required in order to ensure the stability of the LTC system, in terms of the total number of reallocations within the network of LTC. In particular, Eqs. (21-24) should be used whenever one needs to ensure a minimum number of reallocations within the system. Eqs. (21-22) indicate that no beds are removed from a service and location in a given scenario whenever there is need to reallocate beds to that service and location (α_{sltn}=1); and Eqs. (23-24) are used to avoid a removal of beds whenever new beds are added for that service and location (γ_{slt}=1). The need for using these additional conditions arise when considering countries where the state only finances the effective delivery of services, not being responsible for supporting the payments associated with the reallocation of beds. Under these circumstances, the parameters rC^1_{st} and rC^2_{st} needed for defining the objective function (Eqs. (1-3)) are set to zero, and as a consequence, the stability of the system is no longer ensured.

$$\sum_{p \in S_I} \sum_{\substack{j \in L_I \\ j:(p,j) \in U}} rB_{slpjtn}^{in} - M\alpha_{sltn} \leq 0 \;\; \forall s \in S_I, l \in L_I : (s,l) \in U, (t,n) \in Q \tag{21}$$

$$\sum_{p \in S_I} \sum_{\substack{j \in L_I \\ j:(p,j) \in U}} rB_{slpjtn}^{out} \leq (1 - \alpha_{sltn})M \;\; \forall s \in S_I, l \in L_I : (s,l) \in U, (t,n) \in Q \tag{22}$$

$$aB_{slt} - M\gamma_{slt} \leq 0 \;\; \forall s \in S_I, l \in L_I : (s,l) \in U, t \in T \tag{23}$$

$$rB_{slpjtn}^{out} \leq (1 - \gamma_{slt})M \;\; \forall (s,p) \in S_I, (l,j) \in L_I : (s,l) \in U, (p,j) \in U, (t,n) \in Q \tag{24}$$

Satisficing equity levels: Four satisficing equity levels are considered in this study: equity of access (EA; Eqs. (25-28)), equity of utilization (EU; Eq. (29)), socioeconomic equity (SE; Eqs. (30-31)) and geographical equity (GE; Eqs. (32-33)). More details on the selected measures used for defining equity of access, socioeconomic equity and geographical equity have been presented in section 4.2.1. The same equity measures are used in the study presented in this chapter. However, in the context of this study, DMs are asked not to indicate which targets are to be achieved, but which satisficing equity levels (which may be eventually lower than targets) need to be respected or are acceptable [22]. We consider an additional satisficing equity level – equity of utilization – whose measure has a similar structure to the geographical equity measure, differing by ensuring a minimum service level (in comparison to need) across different typologies of LTC services (rather than ensuring a minimum level of service across geographical areas). As shown in the results of Chapter 3, disregarding this objective can create inequalities in the utilization of different types of LTC services.

$$\sum_{n:(t,n) \in Q} \rho_n \left(\frac{t_{tn}^{tot} + t_{tn}^{pen}}{t_{tn}^{\max}} \right) \leq EA_t \;\; \forall t \in T \tag{25}$$

$$t_{tn}^{tot} = \sum_{d \in D} \sum_{g \in G} \sum_{s \in S_I} \sum_{\substack{l \in L_I \\ l:(s,l) \in U \\ l:(d,l) \in F}} t_{dl} R_{dgsltn} D_{dgstn} \;\; \forall (t,n) \in Q \tag{26}$$

$$t_{tn}^{pen} = \sum_{d \in D} \sum_{g \in G} \sum_{s \in S_I} mT \left(D_{dgstn} - \sum_{\substack{l \in L_I \\ l:(s,l) \in U \\ l;(d,l) \in F}} R_{dgsltn} D_{dgstn} \right) \forall (t,n) \in Q \tag{27}$$

$$t_{tn}^{max} = \sum_{d \in D} \sum_{g \in G} \sum_{s \in S_I} D_{dgstn} \, mT \;\; \forall (t,n) \in Q \tag{28}$$

$$\sum_{n:(t,n) \in Q} \rho_n \left(1 - \frac{uR_{stn}}{uD_{stn}} \right) \leq EU_t \;\; \forall s \in S, t \in T \tag{29}$$

$$\sum_{n:(t,n) \in Q} \rho_n \left(1 - \frac{gR_{tn}}{gD_{tn}} \right) \leq SE_t \;\; \forall t \in T \tag{30}$$

$$gR_{tn} = \sum_{d \in D} \sum_{g \in G_P} \sum_{s \in S} \sum_{\substack{l:(s,l) \in U \\ l:(d,l) \in F}} R_{dgsltn} D_{dgstn} \quad \forall (t,n) \in Q \tag{31}$$

$$\sum_{n:(t,n) \in Q} \rho_n \left(1 - \frac{rR_{dtn}}{rD_{dtn}}\right) \leq GE_t \quad \forall d \in D, t \in T \tag{32}$$

$$rR_{dtn} = \sum_{g \in G} \sum_{s \in S} \sum_{\substack{l:(s,l) \in U \\ l:(d,l) \in F}} R_{dgsltn} D_{dgstn} \quad \forall d \in D, (t,n) \in Q \tag{33}$$

5. Case study

This section analyzes the results from applying the LTC_{2SS} model to the county level in the Great Lisbon region. This region belongs to the Portuguese health region with the lowest relative supply of LTC services [84]. The model is applied to the 2014-2016 period, i.e., medium-term, since it has been defined that the Portuguese LTC network should be restructured so as to cover all the associated needs until 2016 [93]. Notwithstanding, the model can be used for building a LTC network for a wider (long-term) time span. The dataset in use and the results obtained are described in this section.

5.1. Model implementation and dataset used

The LTC_{2SS} model was implemented in the General Algebraic Modeling System (GAMS) 23.7 and was solved with CPLEX 12.0 on a Two Intel Xeon X5680, 3.33GHz computer with 12GB RAM. The part of the dataset not related to uncertainty includes:

- LTC supply at the beginning of 2012 in the Great Lisbon region (more details can be found in [94]);
- Operational and investment costs from [24,95-96]. Reallocation costs are not taken into account in this application ($rC^1_{st}=rC^2_{st}=0$), since the Portuguese state is responsible for financing the delivery of IC, having a very limited role as a IC provider [7];
- Travel time (in minutes) between each county in the Great Lisbon region and each LTC service (details on this data can be found in [97]); and maximum travel time allowed for LTC patients accessing IC services from [98] (see Appendix);
- Number of hours of care that need to be provided by physicians (r=1) and nurses (r=2) per individual receiving each type of LTC service from [82] (see Appendix);
- Efficiency factor associated to the provision of services with a score of 1, given that providers in the Portuguese system are paid according to utilization [80];
- Satisficing equity levels that should be defined by DMs in the LTC sector.

In addition to this data, uncertainty was considered in the estimates of two parameters, namely:

- The number of individuals requiring IC (including CC, MTRC, LTMC and PC services), HBC and AC, disaggregated by socioeconomic groups (very low income [VLI] , s=1, and not very low income [NVLI] , s=2, groups), as predicted by the detailed simulation model proposed in Chapter 2;

- The LOS associated to each type of IC service, estimated with data from [24].

In this study, a scenario tree with a finite number of scenarios is used to describe these uncertain parameters (section 4.3.5 explains how to build such a scenario tree). The probability distributions associated to the number of individuals in need of LTC are taken from the outputs of the simulation model developed in Chapter 2 of this thesis. These distributions are then converted into three scenarios using the extended Pearson-Tuckey method [99], i.e., using the 5th, 50th and 95th quantiles and attaching them the 18.5%, 63% and 18.5% probabilities, respectively. Using information from [24], it was also possible to build a probability distribution for the LOS of each type of IC service; and the extended Pearson-Tuckey method was again used to convert these distributions into three scenarios. Note that underlying the use of the Person-Tuckey method is the assumption that the probability distributions that describe these two uncertain parameters are symmetrical [99].

5.2. Selected planning contexts

Different planning contexts were selected for running the LTC_{2SS} model:

- Planning context 0 – the model is run in a deterministic mode assuming average values for the number of individuals in need and LOS and considering the policy strategy (PS) IV from Fig. 1, thus aiming to analyze which changes are needed in the current network of LTC when no uncertainty is accounted for;
- Planning context I – the model is run considering uncertainty on the number of individuals in need and LOS and considering the PS IV from Fig. 1, thus allowing the direct comparison with the results obtained in a deterministic mode (i.e., under planning context 0) and to determine the impact of uncertainty on planning decisions;
- Planning context II – the model is run considering uncertainty on the number of individuals in need and LOS and considering the PS II (hereafter called planning context II.1) and PS III (hereafter called planning context II.2) from Fig. 1, thus allowing analyzing the influence on the network of care of following different strategic health policy options;
- Planning context III – the model is run considering uncertainty on the number of individuals in need and LOS, considering the PS IV from Fig. 1 and neglecting one satisficing equity level at a time, thus allowing to determine the cost of ensuring distinct satisficing equity levels.

Planning context I is taken as the base case, and the results obtained for planning contexts II and III are compared with that case. The base case considers the PS IV from Fig. 1 as the baseline policy strategy, meaning that:

- Converting acute hospitals into LTC units is not allowed, and so there is no need to consider additional locations for IC provision;
- The transfer of financial resources from the acute sector to the LTC sector is done, and we thus assume that no budget constraints need to be considered;

- An institutional-based paradigm is followed, there being no transfer of IC patients to receive HBC as a substitute service.

PS II and PS III are considered when running the model under planning context II, and differ from PS IV by allowing the conversion of acute hospitals into LTC units in PS II and by defining a community-based provision paradigm in PS III. We consider the satisficing equity levels to be the same for all the planning contexts under analysis.

A summarized description of the key parameter values for these different planning contexts is shown in Table 2.

Table 2 Planning contexts under study

Planning contexts		**Planning question**	**Number of individuals in need and LOS**	**Satisficing equity levels per time period *t* (*t*=1,2,3)**	**Policy strategy**
0		Which changes are needed in the current network of LTC when considering average values, under a deterministic case?	Average values	EA_t={0.8;0.78;0.76} EU_t={0.8;0.75;0.7} SE_t={0.6;0.55;0.5} GE_t={0.8;0.78;0.76}	PS IV
I (base case)		Which is the impact on planning decisions when considering the uncertainty on the number of individuals in need and LOS?	Uncertain		
II	**II.1**	Which is the impact on planning decisions of converting an acute hospital into a LTC unit?			PS II
	II.2	Which is the impact on planning decisions of changing to a community-based provision paradigm?			PS III
III		Which is the cost of equity of access?		Neglecting EA_t	PS IV
		Which is the cost of equity of utilization?		Neglecting EU_t	
		Which is the cost of socioeconomic equity?		Neglecting SE_t	
		Which is the cost of geographical equity?		Neglecting GE_t	

5.3. Main results

5.3.1. Planning context 0

In planning context 0 we analyze which changes are needed to the Great Lisbon current LTC network when considering average values, under the deterministic case.

According to the model's results, LTMC is the type of IC service with the highest bed capacity requirements throughout the planning horizon, and this is mainly due to the associated higher LOS when compared to the remaining IC services [84]. Reporting key results for this type of IC service, Fig. 4 shows which changes are needed in the provision of LTMC services, in terms of services' location, bed capacity and allocation of individuals in need to services, over the 2014-2016 period. For simplification purposes, institutions in each county are numbered – e.g., there are two institutions in Lisbon, and these are named Lisbon (1) and Lisbon (2).

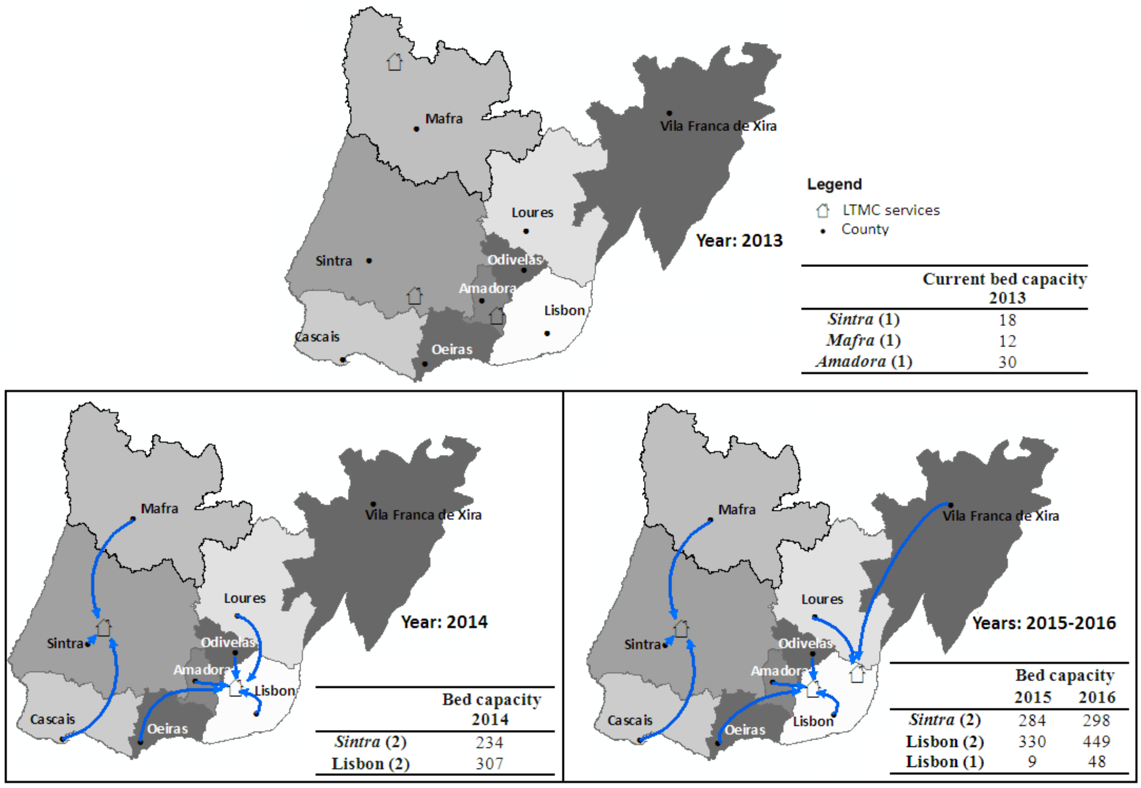

Fig. 4 Changes in the provision of long-term and maintenance care (LTMC) services within the LTC network, in terms of services' location, bed capacity and allocation of individuals in need to services (given by the blue arrows), over the 2014-2016 period under planning context 0

With respect to HBC and AC, Table 3 summarizes the total number of hours of care to be provided by physicians and nurses in each one of these services.

Table 3 Evolution of the total number of hours of care to be provided by physicians and nurses for home-based care (HBC) and ambulatory care (AC) provision under planning context 0

		2014	2015	2016
Physicians	**HBC**	43,706	56,791	70,645
	AC	210,484	255,538	317,967
Nurses	**HBC**	470,680	611,590	760,788
	AC	2,266,754	2,751,945	3,424,260

Table 4 shows the costs associated with operations and investments. These costs are clearly higher than the current budget available for operations and investments in the Great Lisbon area (€5,000,000 and €15,000,000 for investments and operations per year, respectively [100]).

Table 4 Costs for operations and investments within the network of LTC services over the 2014-2016 period under planning context 0

Costs	2014	2015	2016	Sub-total costs for the three year period
Investment costs	€13,740,000	€5,020,000	€5,980,000	€24,740,000
Operational costs	€33,400,000	€41,800,000	€47,560,000	€122,760,000
Total costs for the three year period	€147,500,000			

5.3.2. Planning context I (base case)

In Planning context I it is analyzed how the LTC network should evolve when considering the uncertainty surrounding the number of individuals in need of LTC and LOS. A comparison with the deterministic case (planning context 0) is made. The LTC_{2SS} model is run using the scenario tree built as described in section 4.5.1, assuming the baseline policy strategy (PS IV) and the satisficing equity levels shown in Table 2.

When comparing the obtained results with the ones obtained for planning context 0, several differences arise. There are differences regarding the opening and closure of services (see Fig. 4 vs. Fig. 5). In particular, it can be seen that under planning context I the LTMC service currently operating in *Amadora* (1) should be operating until 2015 (inclusively) (Fig. 5), whereas in planning context 0 this service should be closed in 2014 (Fig. 4). Also while the opening of an additional LTMC service should take place in Lisbon (1) in 2015 under planning context 0 (Fig. 4), in planning context I a new service should be opened in *Loures* (1) in 2016 (Fig. 5). The comparison of Figs. 4 and 5 also shows differences on the allocation of patients to services and on the bed capacity used in each service, but these differences also vary with the scenario in analysis (note that Fig. 5 reports the results obtained for one specific scenario, that in this case is the one with the number of individuals in need and the LOS at their average values).

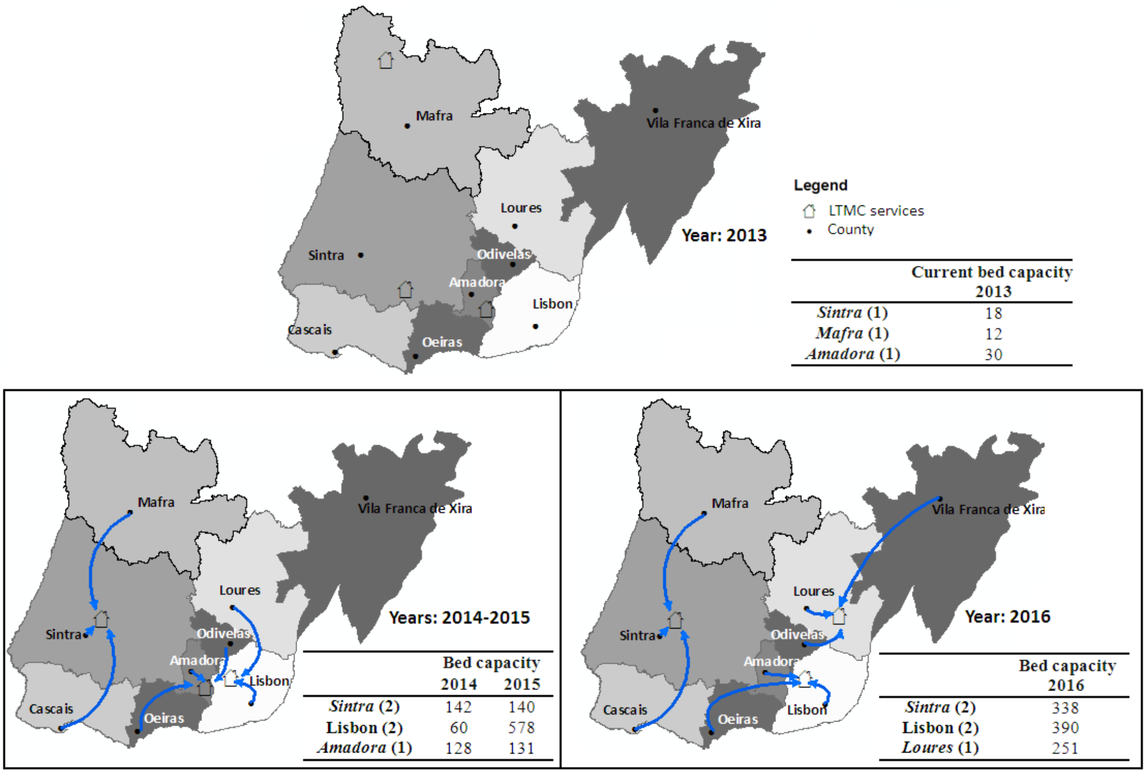

Fig. 5 Changes in the provision of long-term and maintenance care (LTMC) services within the LTC network, in terms of services' location, bed capacity and allocation of individuals in need to services (given by the blue arrows), over the 2014-2016 period under planning context I (for the scenario characterized by average values for the number of individuals in need and the LOS)

For a more detailed analysis on the bed capacity in use in each IC service under planning context I, one can use as example the unit in *Sintra* (2), since this should provide all the types of IC services over the 2014-2016 period (see Fig. 6). The average values in Fig. 6 correspond to the expected bed capacity in use under planning context I, whereas extreme values correspond to the maximum and minimum values obtained for this bed capacity for the same planning context. These results show that the impact of uncertainty increases as the time passes by, with a higher range of values being recommended for the bed capacity in use in each service at the end of the planning horizon. The number of hours of care provided in IC services by physicians and nurses presents a similar behavior.

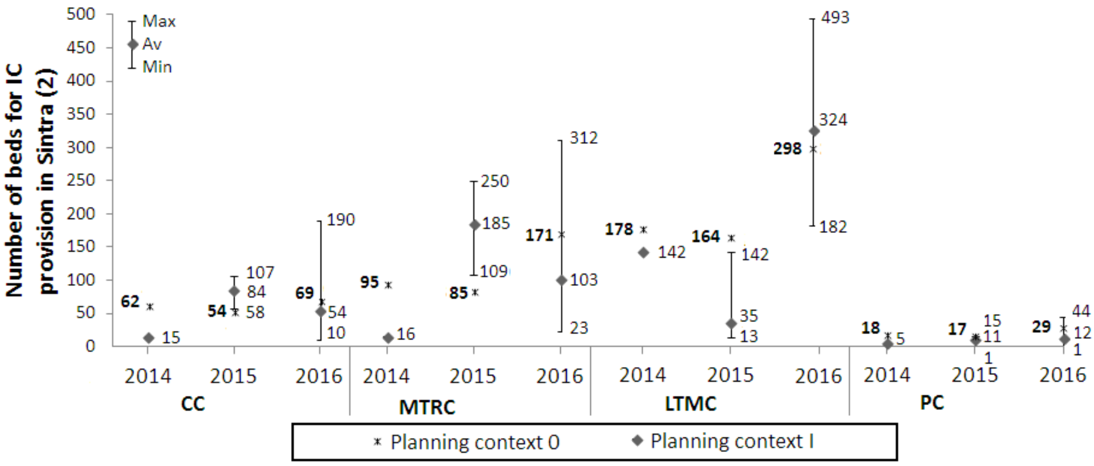

Fig. 6 Bed capacity in use in convalescence care (CC), medium-term and rehabilitation care (MTRC), long-term and maintenance care (LTMC) and palliative care (PC) services provided in *Sintra* (2) throughout the planning horizon under planning contexts 0 and I – the average values correspond to the expected bed capacity in use under planning context I, whereas extreme values correspond to the maximum and minimum values obtained for this bed capacity under planning context I

Additional information useful for planning is generated by the model. For example, Fig. 7 shows the distribution of bed capacity in the LTMC service provided in *Sintra* (2) across individuals belonging to different socioeconomic groups (VLI and NVLI groups). Here it can be seen that a higher priority is given to VLI individuals. In 2014 and 2015 no bed is assigned to NVLI individuals, which is something that cannot be verified for VLI individuals, since a satisficing socioeconomic equity level is used, imposing a minimum service level for this group of individuals. This type of analysis can also be performed for the hours of care provided by physicians and nurses in IC services.

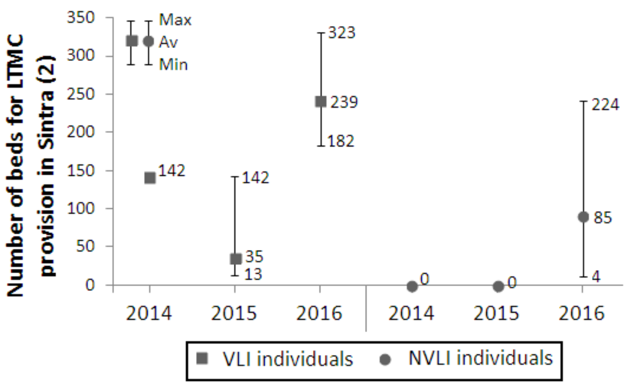

Fig. 7 Bed capacity in use in the long-term and maintenance care (LTMC) service provided in Sintra (2) for very low income (VLI) and not very low income (NVLI) individuals throughout the planning horizon under planning context I

Although the capacity in use in each service varies across scenarios (as shown in Figs. 6 and 7), the number of new beds in which there is a need to invest for each service is defined in the first-stage of the model, taking the same value across scenarios. Table 5 compares the number of new beds that are needed for all the types of IC services under planning contexts 0 and I, showing that there is a need of greater investment in new beds when uncertainty is accounted for – 1,364 new beds are needed under planning context I, while only 1,237 new beds are needed under planning context 0.

Table 5 Additional beds in which there is need to invest under planning contexts 0 and I

	Planning context 0			**Planning context I**		
	2014	**2015**	**2016**	**2014**	**2015**	**2016**
CC	123	51	15	12	44	0
MTRC	205	157	86	82	111	102
LTMC	305	41	172	176	401	429
PC	54	2	26	4	3	0
Total additional bed capacity for the three year period		1,237			1,364	

Since a higher investment in additional beds is expected under planning context I, some low demand scenarios will be characterized by a bed capacity that is higher than required. This is an expected result, since we follow the approach suggested by Birge and Louveaux [37] and defined that the total bed capacity that needs to be in place in each service and location cannot be less than the bed capacity required in each scenario. This is the reason why we refer to '*bed capacity in use*' when describing the results shown in Figs. 5, 6 and 7, since these results refer to the bed capacity effectively in use.

An additional result that comes up from the analysis of Table 5 is that the bed capacity that is required in all the types of IC services should increase so as to ensure that all the equity satisficing levels are achieved. Thus an even higher increase would be needed to satisfy all the demand for LTC. These results suggest that an inadequate supply of LTC currently exists in the Great Lisbon region.

Differences also arise when comparing the results obtained for HBC and AC provision under planning contexts 0 and I, namely, on the number of hours of care to be provided by physicians and nurses. Comparing the results summarized in Tables 3 and 6, it can be seen that a lower number of hours of care is recommended for 2014 and 2015 and a higher number is recommended for 2016 (for both physicians and nurses) under planning context I. Similarly to Fig. 6, Table 6 reports average values that correspond to the expected number of hours of care that is needed under planning context I, as well as the associated maximum and minimum values.

Table 6 Evolution of the total number of hours of care (average values) to be provided by physicians and nurses for home-based care (HBC) and ambulatory care (AC) provision under planning context I

		2014	2015	2016
Physicians	**HBC**	42,838	54,473	71,956
	AC	206,064	254,543	319,870
Nurses	**HBC**	461,328	608,173	764,768
	AC	2,219,148	2,741,232	3,439,330

One should be aware that no differences exist on the location of HBC and AC services. This because it is assumed that these services are provided in the PHCC belonging to the place of residence of individuals in need, and so there is no reallocation of individuals from one PHCC to another, as well as no openings or closures of PHCCs.

Table 7 shows that higher investment costs are required under planning context I – a total investment of €27,260,000 for the entire planning period, whereas €24,740,000 is the amount required for the same period under planning context 0 (Table 4). This is an expected result due to the higher investment needed for adding new beds in the LTC network under planning context I. On the other hand, the total expected cost is slightly lower than the one associated with planning context 0, as a result of a lower number of home-based and ambulatory places under planning context I.

Table 7 Expected costs for operations and investments within the network of LTC services over the 2014-2016 period under planning context I

Costs	2014	2015	2016	Sub-total costs for the three year period
Investment costs	€5,480,000	€11,180,000	€10,600,000	€27,260,000
Operational costs	€22,300,000	€39,000,000	€55,500,000	€116,800,000
Total costs for the three year period	€144,060,000			

5.3.3. Planning context II

Planning context II evaluates the impact on the network of care when different strategic policy options are followed. Two different situations are explored for that purpose, and these take into account different policy strategies, namely, PS II and PS III, as defined in Table 2.

Planning context II.1

As a first analysis, one should consider that DMs in the LTC sector in Portugal consider the possibility to convert acute hospitals into LTC units, i.e., that there are structures with bed capacity installed that can be used for IC provision. In such situations, this structure and bed capacity becomes part of the LTC network with no substantial associated investments (investments will only be required if one decides to install more beds than the ones that currently exist in that hospital). As an illustrative example, we consider that *Maternidade Dr. Alfredo da Costa*, which is a NHS hospital located in the county of Lisbon, is to be closed (note that the closure of this unit is currently under evaluation [101]) and converted into a LTC unit. The LTC_{2SS} model is thus run by introducing this additional location as a new potential location for IC provision (hereafter called Lisbon (3)) with 209 new beds available for that purpose, being this the only difference from planning context I.

Key differences arise when comparing the results obtained under planning contexts I and II.1, i.e., when moving from PS IV to PS II. Regarding the opening and closure of services for planning context II.1, Lisbon (3) should be used for providing CC, MTRC, LTMC and PC services, whereas Lisbon (2) should be definitely closed. This differs from the decisions planned under planning context I, where Lisbon (2) is recommended to be used for providing the four types of IC services. Another difference is related to the number of new beds in which to invest and the expected cost associated with the reorganization of the network (see Fig. 8). Since the new hospital brought 209 additional beds for the LTC system without any additional investment, the number of new beds in which there is a need to invest under planning context II.1 is lower (1,158 beds instead of 1,364 beds, as recommended under planning context I), which then results in a lower investment cost for the entire planning horizon (€23,167,000 instead of €27,260,000). Regarding the supply of HBC and AC services, no significant differences exist between planning context I and II.1.

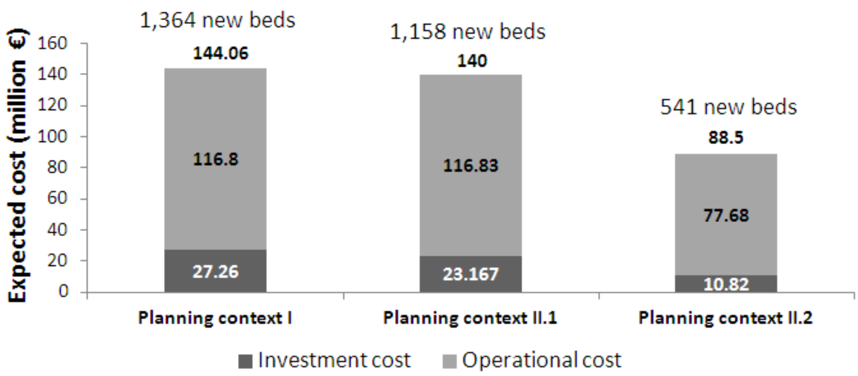

Fig. 8 Key differences found between planning contexts I, II.1 and II.2 for the three year period (2014-2016)

Planning context II.2

In a second analysis we consider relevant to analyze which changes to the organization of the LTC network are required when DMs decide to change from an institutional-oriented to a community-oriented paradigm in LTC provision (i.e., when moving from PS IV to PS III). For that purpose, the LTC_{2SS} model is run imposing that half of those requiring IC will receive HBC instead of receiving IC, being this the only difference from planning context I.

Comparing the results obtained under planning contexts I and II.2 (see Fig. 8), it can be seen that the number of new beds is much lower under planning context II.2 (541 beds instead of 1,364 beds, as recommended under planning context I), mainly because half of those needing IC will receive HBC as a substitute service for IC (or no service at all). Also there is a global decrease in the hours of care provided by both physicians and nurses (as shown in Fig. 9), and this happens because IC typically requires an higher amount of hours of care (per individual in need) when compared to HBC [82]. As a result, lower investment and operational costs are associated with planning context II.2 (as shown in Fig. 9).

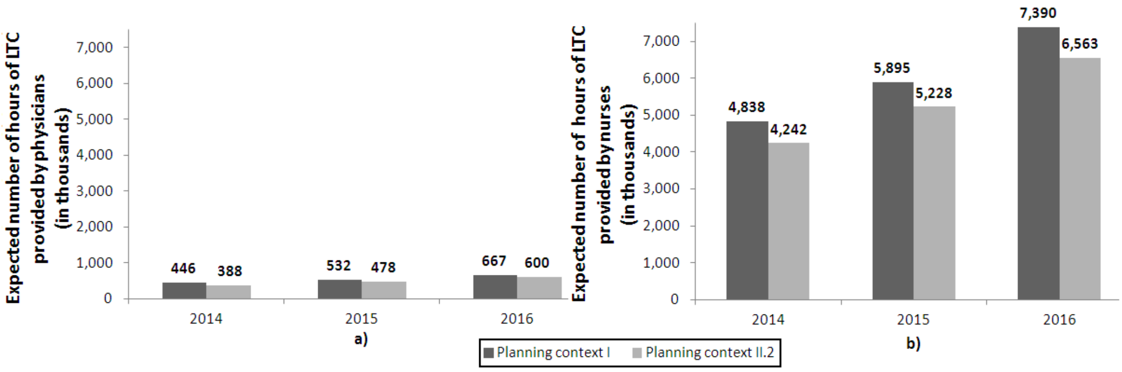

Fig. 9 Expected number of hours of LTC (in thousands) provided by a) physicians and b) nurses over the planning horizon under planning contexts I and II.2

5.3.4. Planning context III

This section explores the following questions: which is the cost associated with ensuring equity satisficing levels? To calculate the cost of each equity dimension, the LTC_{2SS} model was run by imposing all the equity satisficing levels except the one whose cost we want to determine, and analyzing between the total cost in planning context I (€144,060,000, as shown in Table 7) and the total cost in this case. Table 8 presents the key results for the four equity costs.

Table 8 Estimates for the cost of ensuring equity satisficing levels

Cost of equity	
a) Cost of ensuring equity of access satisficing level (EA)	€460,000
b) Cost of ensuring equity of utilization satisficing level (EU)	€67,890,000
c) Cost of ensuring socioeconomic equity satisficing level (SE)	€60,000
d) Cost of ensuring geographical equity satisficing level (GE)	€460,000

From the analysis of Table 8 it can be said that the type of equity associated with a higher cost is EU, whereas SE is the type of equity with the lowest cost. These costs represent the extra amount required to ensure the achievement of the corresponding satisficing equity level. For instance, if DMs in the LTC sector disregard the achievement of EU satisficing levels, a lower amount of €67,890,000 is required in the planning of LTC.

By neglecting the EU, the model will tend to concentrate resources in services with a lower LOS in the first place, as these tend to be cheaper and allow for providing services to a higher number of individuals.

In short, the analysis of these different planning contexts shows that a significant reorganization and increase in installed capacity (both in terms of beds and human resources) needs to be carried out in the Great Lisbon region. This suggests that an inadequate supply of LTC currently exists in the area. Results also show that different decisions arise when one moves from a deterministic model to a stochastic model that considers the uncertainty on LTC demand; and that it is relevant to consider which strategic health policy decisions are selected by governments, as they impact in the configuration and costs of the LTC network. Results illustrate how the LTC_{2SS} model can provide detailed information for policy makers and planners in the LTC sector, such as information on the capacity disaggregated by location, service and the respective groups of individuals which are expected to receive care.

5.3.5. Computational results

Table 9 displays the computational results obtained when applying the LTC_{2SS} model for each planning context. As expected, a growth in the number of variables and constraints is observed when one moves from the deterministic to the stochastic model. The computational time required to run the stochastic model for the different planning contexts is also much higher when compared to the computational time required to run the deterministic model. For the stochastic case, a maximum time of 7200 CUs was assumed and for that lower gaps were obtained. This CU time is considered as adequate since strategic and tactical decisions are at stake.

Table 9 Computational results

Planning context	Total variables	Integer variables	Total constraints	Iterations	CPU (sec.)	Gap (%)	Objective
0	12,430	5,292	17,653	3,455	2	0	€147,493,020
I	181,506	67,900	266,795	39,305,625	7,200	0.11	€144,060,505
II.1	217,974	83,616	329,750	30,734,764	7,200	0.21	€139,773,581
II.2	181,506	67,900	266,795	37,910,442	7,200	0.09	€88,451,391
III – case a)	181,503	67,900	266,789	40,390,049	7,200	0.21	€143,629,114
III – case b)	181,488	67,900	266,759	14,584,556	7,200	0.96	€76,166,566
III – case c)	181,479	67,900	266,741	32,926,670	7,200	0.47	€143,902,432
III – case d)	181,503	67,900	266,789	19,651,664	7,200	0.11	€143,569,683

6. Conclusions

The increasing need for LTC, along with an inadequate supply of LTC services and with strong budget constraints that many European countries currently face, make LTC planning a priority in the health policy agenda of many European countries. This study proposes a stochastic mixed integer linear programming (MILP) model – the LTC_{2SS} model – to assist the planning of networks of LTC in the context of NHS-based countries, both at a strategic and tactical level. The model considers the impact of demand uncertainty and of different strategic policy options at the health care system level, providing detailed information for planning, both in terms of location selection and capacity planning, by type of LTC service, including institutional, home-based and ambulatory services. The model aims at minimizing expected costs, while ensuring a minimum level of demand satisfaction and considering that policy makers with planning responsibilities in the LTC sector demand that satisficing levels for different types of equity should be ensured, namely, of equity of access, equity of utilization, socioeconomic equity and geographical equity.

This study adds to the literature by: i) proposing a generic approach that informs planning decisions in the LTC sector, being this a health sector with several specificities not widely addressed in the health care literature; ii) proposing a stochastic mathematical programming model that considers the impact of uncertainty while planning changes to a LTC network over an extended planning horizon; iii) considering the wide range of services delivered within a LTC network; iv) considering multiple equity concepts relevant for planning in NHS-based systems; and v) exploring how planning decisions change when different strategic health policy decisions are followed. The model provides detailed information for planning, in particular regarding on: where and when to locate services and with which capacity, both in terms of beds and human resources; how to distribute this capacity across services and patient groups; which changes are needed in this network over time, including capacity increasing or reduction and the opening and closure of services; and which is the minimum cost to implement these changes.

Key results from applying the LTC_{2SS} model to the Great Lisbon region to the 2014-2016 period (i.e., medium-term) confirms that an inadequate supply of services currently exists in the Great Lisbon region. Model results also proved the relevance of considering uncertainty while planning the reorganization of a LTC network, since different decisions arise when uncertainty is accounted for. Considering the impact of different strategic health policy decisions is also relevant, since it significantly affects planning decisions related to setting capacity levels and the geographical distribution of services. In particular, results have shown that the opportunity to convert an acute hospital into a LTC unit and changes in the LTC provision paradigm may have a significant impact on the organization of services, as well as on costs. One should note that the developed model can be used for supporting planning decisions in the long-term, and not only for the medium-term, as illustrated in this chapter.

As future work, in the sequence of this study, several research topics seem to be worth pursuing. First, for some health care systems, it may be relevant to include multiple objectives in the stochastic model. In particular, the maximization of equity (defined in several forms) and of health gains, as well as the minimization of costs, should be jointly addressed through a multi-objective stochastic mathematical programming model. Also, there is need to explore approaches to solve the stochastic model using a higher number of scenarios since a more realistic picture can be provided with the use of a higher number of scenarios. Furthermore, alternative stochastic approaches should also be explored. For instance, it may be relevant to consider a two-stage stochastic approach where both location and allocation are considered as first-stage decisions. Such an approach would allow obtaining a more stable allocation of patients across scenarios. Further work could include both: adapt and apply the model to different geographic areas and to a larger area and in collaboration with real DMs in the LTC sector; and building a decision support tool that integrates the stochastic model with Geographic Information Systems (GIS) and a user-friendly interface that promotes the use of the model by health care planners in practice. An additional line of further research includes exploring the impact on the network of care of following health policy strategies other than the ones explored in this study. For instance, in line with the policy strategies shown in Fig. 1, an additional possibility would be exploring the impact of transferring human or material resources from the acute care to the LTC sector.

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Appendix

Table A1 presents key data (with no associated uncertainty) used for applying the model to the county level in the Great Lisbon region for the 2014-2016 period.

Table A1 Key dataset (with no associated uncertainty) used for running the model for the LTC network operating in the Great Lisbon area

Notation	Value	Description
iC_{st}	€20,000 (s=1,2,3,4; t=1,2,3)	Investment cost per bed [96].
oC_{st}	€26,268 (s=1,2,3,4; t=1,2,3) €648 (s=5; t=1,2,3) €420 (s=6; t=1,2,3)	Annual operational cost per bed [24,95].
rC^{1}_{st} ; rC^{2}_{st}	0 (s=1,2,3,4; t=1,2,3)	Reallocation cost per bed – this cost is set to zero because the Portuguese state is responsible for financing the delivery of care, having a very limited role as a LTC provider [7].
mT	30 minutes	Maximum travel time allowed for LTC patients accessing institutional services [98].
HRp_{rs}	Physicians (r=1): 64 (s=1,4); 48 (s=2); 32 (s=1); 26 (s=5); 13 (s=6) Nurses (r=2): 770 (s=1); 575 (s=2); 385 (s=1); 512 (s=4); 280 (s=5); 140 (s=6)	Number of hours of care that need to be provided by physicians and nurses per individual receiving LTC [82].
EA_t	0.8 (t=1); 0.78 (t=2); 0.76 (t=3)	Satisficing equity levels that are assumed to be defined by DMs in the LTC sector.
EU_t	0.8 (t=1); 0.75 (t=2); 0.7 (t=3)	
SE_t	0.6 (t=1); 0.55 (t=2); 0.5 (t=3)	
GE_t	0.8 (t=1); 0.78 (t=2); 0.76 (t=3)	