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Water use scenarios as a tool for adaptation to climate change of a water supply company

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Abstract

The project ADAPTA CLIMA, promoted by EPAL, the largest Portuguese Water Supply Utility, aims to provide the company with an adaptation strategy in the medium and long term to reduce the vulnerabilities of its activities to climate change. We used the special report emissions scenarios (SRES) of the IPCC (Intergovernmental Panel on Climate Change) to produce local scenarios of water use. Available population SRES for Portugal were downscaled to the study area using a linear approach. Local land use scenarios were produced using the following steps: (1) characterization of the present land use for each municipality of the study area using Corine Land Cover and adapt the CLC classes to those used in the SRES; (2) identification of recent tendencies in land use change for the study area; (3) identification of SRES tendencies for land use change in Europe; and (4) production of local scenarios of land use. Water use scenarios were derived considering both population and land use scenarios as well as scenarios of change in other parameters (technological developments, increases in efficiency, climate changes, or political and behavioural changes).

The A2 scenario forecasts an increase in population (+16%) in the study area while the other scenarios show a reduction of resident population (−6 to 8%). All scenarios, but especially A1, show a significant reduction in agricultural area and an increase in urban area. Regardless of the scenario, water use will progressively be reduced until 2100. These reductions are mainly due to increased water use efficiency and reduction of irrigated land. The results concord with several projects modelling water use at regional and global level.

1 Introduction

Climate change has already had effects on the natural environment, and much bigger changes are projected for this century (IPCC, 2007; EEA, 2008). In Europe, especially in the south, water availability and water stress are already a concern (Henrichs

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et al., 2002; EEA, 2008). Climate change will further affect water availability and water consumption (EEA, 2008). Thus, there is a growing scientific and policy interest for water resources analyses on the global and regional scale (Mäerker et al., 2003; Menzel et al., 2007). Climate and socioeconomic drivers such as population and economic growth, land use and technological evolution may have a great impact on water resources and stress (Menzel et al., 2007; Shen et al., 2008).

At the European level, several studies looked into water resources availability and stress in the future (Henrichs et al., 2002; Mäerker et al., 2003; Menzel et al., 2007). However the results differ between authors. Henrichs et al. (2002) projected a reduction in total water withdrawals in Western Europe and attributed that reduction to technological evolution and to households and industry efficiency. Menzel et al. (2007) concluded that in Southern Europe the water stress and water withdrawals will increase due to irrigation demand and climate change.

In Portugal, there are published projections for the future population, such as the National Statistics Institute projections made for the country up to the middle of the XXIst century (INE, 2008) and the study “Climate change: Mitigation Strategies in Portugal” (MISP, 2007) with projections of the SRES scenarios downscaled for Portugal up to the end of the XXIst century.

The project ADAPTA CLIMA-EPAL aims to provide socioeconomic scenarios for population growth, land use and water use for an area which includes the Portuguese basin of the Tagus River (Fig. 1) with all the municipalities that are supplied directly or indirectly by EPAL, and the west aquifers of continental territory of Portugal. In total, 106 municipalities were included in the study area, of which, 34 are supplied by EPAL. Projections of future water withdrawals will contribute to EPAL, as well as to other stakeholders and policy makers. Other tasks of the project will include modelling future climate and water availability. All the produced data will be analysed and used in order to provide data to put in place a robust adaptation strategy to reduce vulnerability to future changes. In this paper we will evaluate potential future water stress for EPAL

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by presenting socioeconomic scenarios for population growth, land use and water use for the project area.

2 Materials and methods

Local scenarios¹ of water use until the end of the century were explored, not only for the EPAL system, but also for all other systems that compete for water resources, such as agriculture. We used the four IPCC SRES scenarios (A1, A2, B1 and B2) (IPCC, 2000) to produce climate and hydrological scenarios for the project. These scenarios are in widespread use, therefore allowing to compare and validate our results (Drunen et al., 2011). The SRES set various scenarios with changes in population, economic growth, technology, energy consumption, and greenhouse gas emissions (IPCC, 2007; Shen et al., 2008). Several studies produced water consumption scenarios for Europe for the XXI century based on SRES (e.g. Seckler et al., 1998; Märker et al., 2003; Flörke, 2005; Alcamo et al., 2007; Bates et al., 2008; Shen et al., 2008; Kok et al., 2009).

Linear regionalization (Fig. 2) of the SRES for the study area was applied, because it is the most transparent and simple method available (Vuuren et al., 2007, 2010). Regionalization followed the next criteria (Vuuren et al., 2006, 2010):

1. Consistency with local data observed (for the historic or base period);
2. Consistency with the original scenario (SRES scenarios);
3. Transparency;
4. Plausibility of the results.

¹ The terminology local scenario was adopted for our results while for IPCC scenarios the term SRES was used. At the national scale, there are also INE's population projections.

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The main steps of the methodology are summarised in Fig. 3. The evolution of water use depends on several factors such as population and land uses (e.g. Boland, 1998; Houghton-Carr et al., 2008). In addition, other parameters were taken into account, namely developments in technology, as well as changes in climate and consumer behaviour.

The downscaling for water use was done following three steps which are outlined below.

2.1 Present water use by activity sector

Data of water use per capita, by sector and municipality, was collected from the following sources: National Water Plan (INAG, 2001), Instituto Nacional de Estatística (INE), EPAL (internal data for the period 2000–2010) and National Inventory of Water Supply Systems and Waste water (INSAAR, 2007).

2.2 SRES scenarios – coefficients of change in demand factors

The water consumption is determined by demand factors. These factors are the following ones:

1. **Population** – The CIESIN (Center for International Earth Science Information Network), has developed a database containing regionalized SRES scenarios for population and GDP at the country scale (CIESIN, 2002). Using the base population of the National Statistics Institute (INE) estimated for 2005 (INE, 2006), local population scenarios for each municipality were built for the study area by applying the CIESIN growth rates downscaled for Portugal. Given the size of the study area (and homogeneous characteristics in relation to the larger area, e.g. Portugal, the linear method of downscaling (O'Neill et al., 2001; Graffin et al., 2004) was considered the most appropriate;

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2. **Land use** – Corine Land Cover² land use classes were reclassified by grouping classes taking into consideration the classes used in SRES (Fig. 3). The sectors of water use considered in the National Water Plan (INAG, 2001) were taken into account. Local land use scenarios change in percentages for each municipality of the study area were produced by applying linear downscaling on the trends of the SRES scenarios for Europe and considering the characteristics of each county and the trends observed in recent years (IPCC, 2007; Schröter et al., 2005; Verburg et al., 2006; Rounsevell et al., 2006). Since Lisbon municipality is already mostly urban, urban expansion for Lisbon municipality was redistributed to neighbouring municipalities. This redistribution to the neighbouring municipalities was done by analysing the recent tendencies (where the closest areas are more likely to grow) and applying the same tendencies for the local scenarios.
3. **Water use efficiency** – we calculated coefficients of change in consumption efficiency for each sector of water use (Fig. 3) and each scenario considering available studies on scenarios of water consumption in Europe for the next century (Sect. 3) (e.g. Seckler et al., 1998, Märker et al., 2003; Flork, 2005; Alcamo et al., 2007; Bates et al., 2008; Shen et al., 2008; Kok et al., 2009);
4. **Behaviour and water pricing policies** – we calculated a coefficient of change in consumption due to changes in behaviours and policies for each sector of water use and each scenario considering the studies referred in the previous point;
5. **Climate** – we calculated a coefficient of change in consumption due to climate change for each scenario and for each sector considering the available climate scenarios for the study area and correlations obtained between consumption rates and climate (SIAM II, 2006; EPAL, unpublished data).

² CLC, 2000 – <http://etc-lusi.eionet.europa.eu/CLC2000/classes/index.html>

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3 Water use projections

None of the studies which produced scenarios for water use in Europe for the XXIst century could be directly applicable in this project for three different reasons. Firstly these studies use different assumptions and scenarios. For example, Shen et al. (2008) and Mark et al. (2003) do not consider changes considered in the SRES like reductions of agricultural area in all scenarios, evaluating only the changes in consumption as a function of changes in climate and behaviours. Secondly, they present scenarios for different time periods. For example, Flörke (2005) presents scenarios only for the 2000–2030 period. And the third reason is that some of these studies do not consider local characteristics and different dynamics between the different European countries.

Analysis of those studies were made to assess the general trends presented but with the intention of applying them to the SRES scenarios and the reality of the study area. Regardless of the study, general trends could be identified and are described below (see also Table 1):

1. Changes in land use, agricultural and industrial production are major forces of changes in water consumption (Mark et al, 2003; Houghton-Carr et al., 2008). All SRES scenarios indicate a significant reduction of the agricultural area (Table 3, Section Results and Discussion);
2. The effects of global warming increase the need for both domestic and agriculture water consumption (Bates et al., 2008). However, these increases should be small, around 5% in 50 yr (Bates et al., 2008). Scenarios A1 and A2 have the highest temperature increases (and larger extensions of dry periods) and thus the largest increases in water consumption needs;
3. Technologies and behaviours might have effects on water consumption. It could drop in all sectors due to technological developments, such as increases in recycled water, improvements in irrigation efficiency and reduction of losses (Mark et al., 2003; Flörke, 2005; Kok et al., 2009). Technological improvements will be

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higher in scenarios A1 and A2. These trends are forced by worsening water shortages. According to Kok et al. (2009), it is likely that the increasing water scarcity in the southern countries of Europe will lead national governments to implement more efficient water rates, helping to reduce demand. The EU will impose more savings and water recycling, as well as sustainable urban drainage systems on a large scale for cities that are in water stress (especially in scenarios A2 and B1). The same authors reported the possibility of using desalination in coastal areas around the Mediterranean to provide water to some metropolitan areas. Water markets provide higher levels of funding for the government to invest in water saving devices at different scales (family, neighbourhood, city, etc.) (Kok et al., 2009). In B1 and B2 scenarios, there will be a tendency to improve water sustainability, reducing waste and reducing consumption per capita;

4. The evolution of population will also have influence in water consumption. This will decrease in all scenarios except A2.

Scenarios were produced for the whole study area (106 municipalities) for water use in the domestic, agriculture, industry and services sectors. Scenarios were also produced for the sub-area supplied by EPAL (34 municipalities) and for the municipalities for which we had data for water use by sector (Lisbon and Batalha). For each sector the following formula was used. Values for each parameter in the formula were obtained considering available publications.

$$C_{\text{Scenario}X_t} = C_b \cdot \Delta \text{Sector}_t \cdot E_t \cdot \text{Comp}_t \cdot \text{Clima}_t$$

where $C_{\text{Scenario}X_t}$ = consumption in the scenario X and year t

C_b = consumption of water in the base year

ΔSector_t = Net change in the demand sector between the base year and year t

(e.g. change in population, agricultural area or industrial activity)

E_t = Coefficient of efficiency gains between the base year and year t

$Comp_t$ = Coefficient of change in behavior between the base year and year t
 $Clima_t$ = Coefficient of change in consumption due to changes in climate between the base year and year t .

4 Results and discussion

5 In Table 1 we compiled the main trends in the forcing factors (land use, population, climate, efficiency, behaviour, politics) which affect water use. Only one scenario (A2) indicates an increase in the resident population of the study area of around 16 % by the end of the century (Fig. 5). The remaining scenarios indicate a reduction in the population from 6 to 8 %. All scenarios, but especially A1, indicate a significant reduction in
10 agricultural area and an increase in urban area (Fig. 6).

The main trends of the SRES for land use changes in Europe, have been identified in several publications (e.g. Schröter et al., 2005; Verburg et al., 2006; Rounsevell et al., 2006; IPCC, 2007) and are resumed in Table 3. All scenarios, but especially A1, show a significant reduction in agricultural area and an increase in urban area.

15 Comparing the results for our local scenarios in the Fig. 6 and the SRES European tendencies from different authors (Schröter et al., 2005; Verburg et al., 2006; Rounsevell et al., 2006; IPCC, 2007) in Table 2, it is possible to see that our local scenarios are coincident in the urban and agriculture land use, but not in grassland. Our results show that this last type of land use will diminish while the European SRES tendencies are to
20 maintain.

Regardless of the scenario, water use will progressively be reduced until 2100 (Table 4). These reductions are mainly due to increased water use efficiency and reduction of irrigated land. Even if a warmer and drier future climate will lead to a rise in water demand for irrigation and for domestic use, none of the scenarios shows an increase in
25 water use. Also, even when we consider a significant increase in population (scenario A2), overall water consumption will be reduced. Our results thus seem to indicate that

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behavioural and technological factors will be the main factors in shaping future water use in the study area.

The projections of future water withdrawals presented in this paper are based on a range of assumptions regarding agricultural, industrial, and domestic water use. That is why we used four different scenarios, which indicate different possible futures in terms of socio-economic developments. All scenarios project reduced water use in all the sectors analyzed, which increases confidence in the results. Furthermore, our results agree with several projects that model water use at a regional or global level (e.g. Seckler et al., 1998; Menzel et al., 2007). Henrichs et al. (2002), for example, have modelled water use up to 2070 by considering a simple scenario where present water use trends are prolonged into the future and have obtained a decrease in water withdrawals in Western Europe, mainly resulting from gains in the efficiency of water use. The experiences of many countries show that water use intensity decreases after reaching a saturation amount, mainly due to industrial restructuring and water use efficiency improvements in production processes (Shen et al., 2008). Thus, although projected changes in water withdrawals strongly depend on the assumptions regarding socio-economic factors such as economic and industrial growth (Henrichs et al., 2002), which are largely uncertain, it seems that most scenarios indicate the same long-term trends in reduction of water use.

However, these results need to be considered carefully, also taking into analysis scenarios of climate and hydrological change. In Portugal, water use is extremely correlated to the temperature, and the warm season is also the dry season, with higher consumption rates. Therefore there is already some predisposition to water stress, especially in the south of continental territory and during summer months. During the 20th century there has been a clear trend towards drier conditions, with decreases in rainfall and moisture availability in most Mediterranean regions; severe drought episodes (from both meteorological and hydrological contexts) have become more frequent and persistent, namely in the Iberia area (Sousa et al., 2011). In Portugal the total annual precipitation has been considerably reduced during the last decades as it rained for less

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number of days (SIAM II, 2006). Global climate models project a decrease in precipitation, an increase in temperatures and evapotranspiration, and an enlarged dry season for the study area (SIAM II, 2006). Our results show that socio-economic changes may reduce water consumption and therefore the risk of increased water stress due to climate change may be lower than previously expected.

5 Conclusions

The results of this study show that all different scenarios considered indicate reductions in water use in the study area. Another important result is that behavioural and technological factors are determinant in shaping future water use in the study area. In Portugal, water use inefficiency corresponds to about 41 % of the total withdrawals as the National Water Plan (2001) referred. Thus, it is not surprising that there can be enormous gains in water efficiency, especially in the agricultural and industrial sectors.

The scenarios are a useful framework for thinking about the future and a fundamental step for EPAL to prepare a long-term adaptation strategy to climate change meant to contribute to the reduction of vulnerability of different future societies. EPAL successful adaptation to climate change is vital for the economic activities and the local population. The tasks that look at the impacts in the resources (quantity and quality of water) will also need to be taken into account in the process, so that the adaptation occurs in a sustainable way. To build a consistent strategy for climate change adaptation, both climate and socioeconomic scenarios are important, while socioeconomic scenarios can decrease the decision failures.

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Table 1. Main trends in the various forcing factors for water use for each scenario. Legend: (+) indicates an increase, (++) indicates a substantial increase, (\approx) indicates no change or very small changes, (–) indicates a decrease; (– –) indicates a substantial decrease.

	A1	A2	B1	B2
Coefficient of industrial growth	++	\approx	\approx	\approx
Coefficient of change in industry water use due to efficiency	--	–	--	–
Total Industry Water Use	+	–	–	–
Agricultural area	--	--	–	–
Coefficient of change in water use for crops due to climate change	++	++	+	+
Coefficient of change in agricultural water use due to efficiency	–	–	–	–
Total Agriculture Water Use	--	--	–	–
Population	–	+	–	–
Coefficient of change in behaviour	\approx	\approx	–	–
Coefficient of change in consumption due to climate change	+	+	+	+
Coefficient of change in domestic water consumption due to efficiency	–	–	–	–
Total Domestic Water Use	–	\approx	--	--

Source: Adaptaclima-EPAL project report (2011).

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Table 2. Percentage of Growth on the INE (2008) projections and scenarios of CIESIN (2002).

	CIESIN B2	CIESIN A2	CIESIN A1 e B1	INE central	INE low	INE high	INE without migrations
% total grow 2005–2060	–8.33 %	3.76 %	–0.86 %	–1.94 %	–15.70 %	13.47 %	–23.32 %
% total grow 2005–2100	–6.07 %	19.61 %	–8.09 %				

Source: Adaptaclima-EPAL project report (2011).

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Table 3. Main trends in land use changes in the SRES for Europe.

	A2	A2	B1	B2
Agriculture	---	--	--	-
Urban	+++	++	++	+
Industry	+	+	+	≈
Biofuel	+	+	++	+
Forests	++	+	+	+++
Grassland	≈	≈	≈	≈
Protected Areas	+	≈	++	++

Adaptaclima-EPAL project report (2011).

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Table 4. Water consumption by sector in the project study area Adaptaclima-EPAL in the base year (2000) and scenarios (percent of base year values) for 2080. 1 – Baseline data: National Water Plan 2001, Corine Land Cover 2000, 2 – Baseline data: INSAAR 2007, Corine Land Cover 2000.

	Base year (m ³)	A1	A2	B1	B2
Agriculture ¹	1 443 548 958	22.7 %	46.6 %	37.5 %	52.2 %
Industry ²	2 194 069	60.2 %	59.4 %	28 %	58.3 %
Domestic ²	237 702 531	87.60 %	98.25 %	48.72 %	49.77 %
Services ²	6 466 211	65.70 %	63.90 %	48.72 %	74.12 %

Source: Adaptaclima-EPAL project report (2011).

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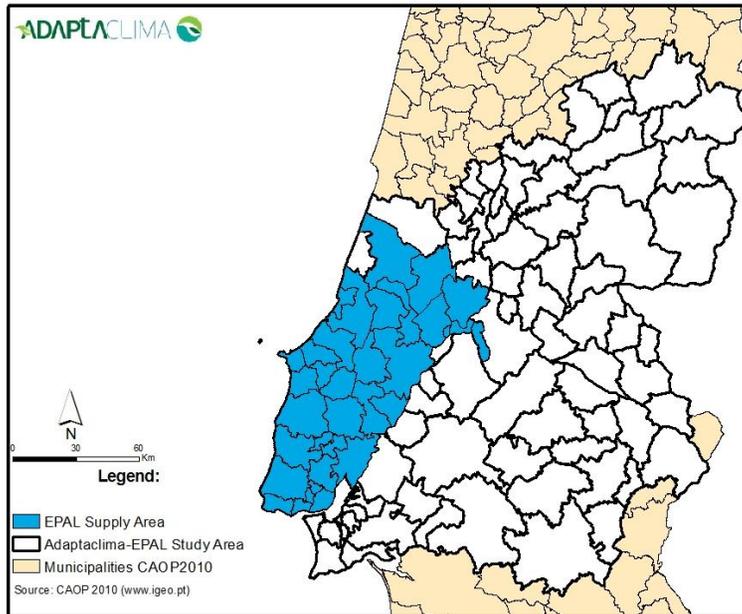


Fig. 1. Study Area. Source: Adaptaclima-EPAL project report (2011).

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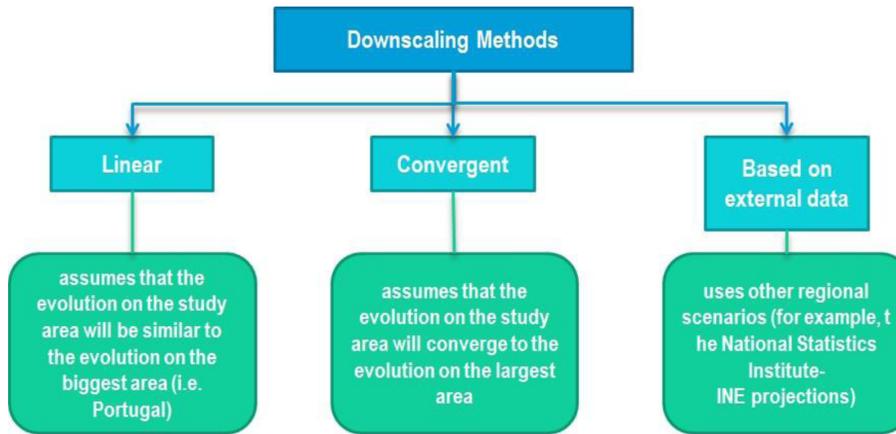


Fig. 2. Downscaling methods in Socioeconomic Scenarios. Source: adapted from Vuuren et al. (2006).

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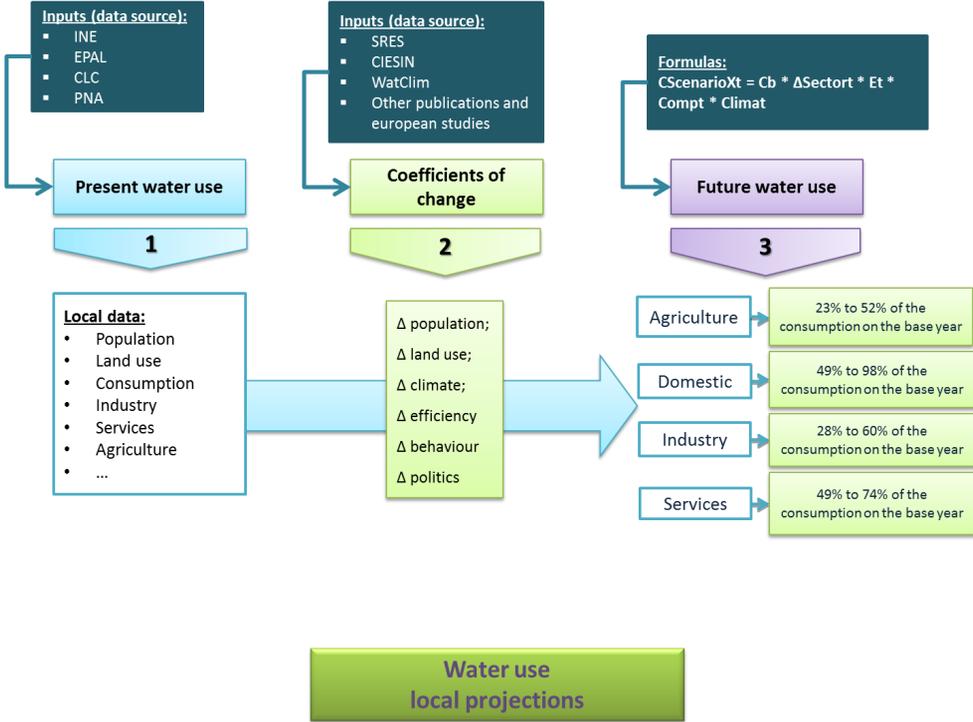


Fig. 3. Resumed methodology for water withdrawals projections. Source: Adaptaclima-EPAL project report (2011).

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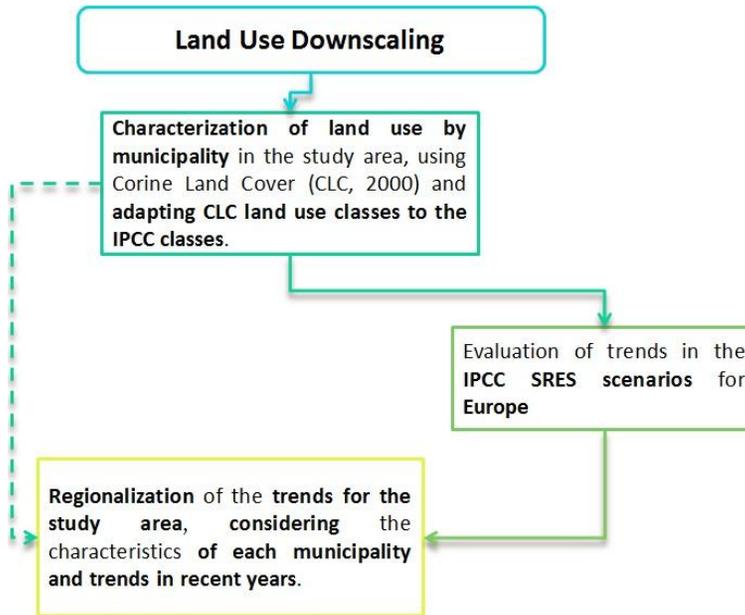


Fig. 4. Land Use Downscaling Methodology. Source: Adaptaclima-EPAL project report (2011).

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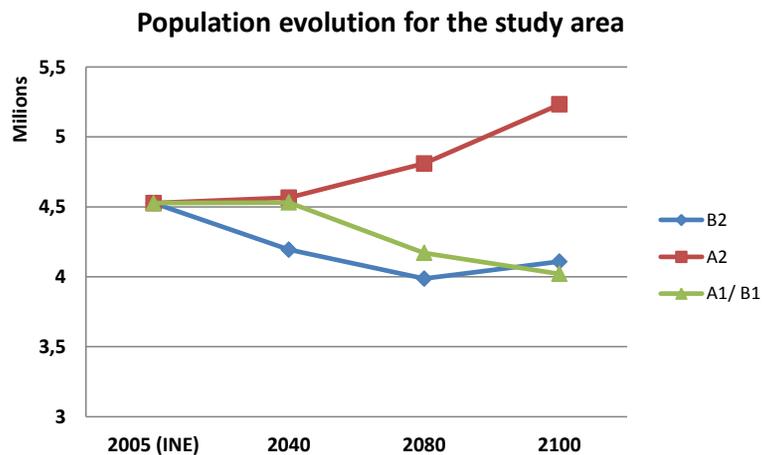


Fig. 5. Population local scenarios. Source: Adaptaclima-EPAL project report (2011).

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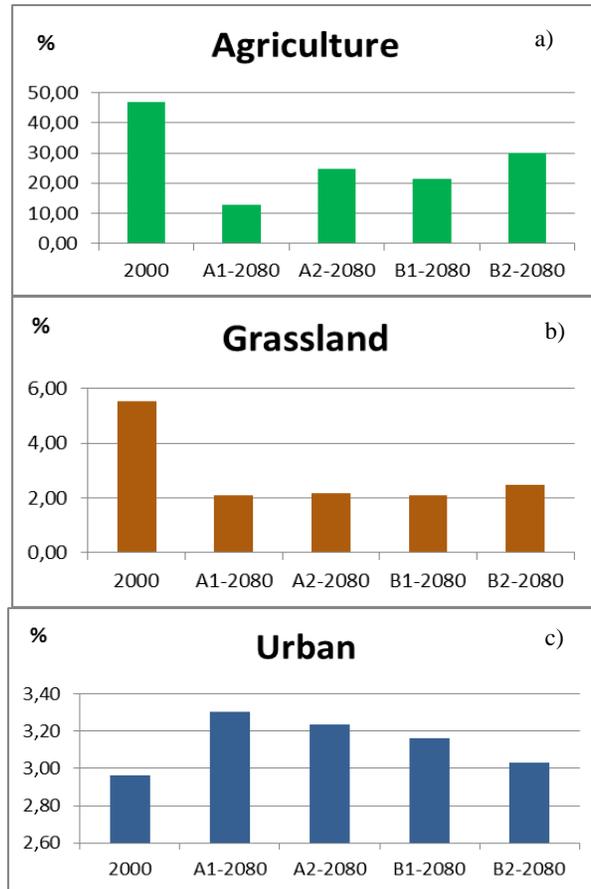


Fig. 6. Local scenarios for land use change for: **(a)** agriculture, **(b)** grassland and **(c)** urban. Source: Adaptaclima-EPAL project report (2011).