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The impact of global changes on economic values of water for Public Irrigation Schemes at the São Francisco River Basin in Brazil

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Abstract

Economic values of water for the main Public Irrigation Schemes in the Sub-Middle region of the São Francisco River Basin, in northeastern Brazil, are determined in this study using an integration of a global agro-economic land and water use (MAgPIE) with a local economic model (Positive Mathematical Programming). As in the latter the water values depend on the crops grown, and as Brazilian agriculture is strongly influenced by the global market, we used a regionalized version of the global model adapted to the region in order to simulate the crop land use, which is in turn determined by changes in global demand, trade barriers, and climate. The allocation of sugarcane and fruit crops projected with climate change by the global model, showed an impact on the average yields and on the water costs in the main schemes resulting in changes in the water values locally. The economic values for all schemes in the baseline year were higher than the water prices established for agricultural use in the basin. In the future, these water values will be higher in all the schemes. The highest water values currently and in the future were identified in municipalities with a significant proportion of area growing irrigated sugarcane. Being aware of current water values of each user in a baseline year and in a projected future under global climate and socio-economic changes, decision makers should improve water allocation policies at local scale, in order to avoid conflicts and unsustainable development in the future.

Keywords
Economic value of water; water pricing; São Francisco River Basin; semi-arid region; Positive Mathematical Programming; global model.

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1.Introduction

Irrigation plays a special role for agricultural production in northeastern Brazil. Eighty percent of this area is semi-arid, and it is one of the poorest regions in the country, where the dry season can last up to 11 months (EMPRAPA 2008; MIN 2005). Irrigated areas in the Northeast region increased by 1.155 million hectares between 1960 and 2006, thus constituting 26% of the area equipped for irrigation in Brazil (FAO 2016). The main water source for this semi-arid region is the São Francisco River which, along with the Parnaiba river, are the only rivers in the Northeast that don´t have intermittent flows. The São Francisco River Basin has the third largest irrigated area within a basin in Brazil and the largest in the Northeast. The river dominates the region, but the topography generally requires that its water be extracted by pumping. Its main consumptive water use is irrigation which along with livestock watering (small part) drew 70% of withdrawals in 2008, as compared to a national average of 60% (ANA 2009; FAO 2016).

In Brazil´s Northeast, irrigated agriculture is principally developed in Public Irrigation Schemes (PIS) where water supplies and infrastructure are subsidized by government funds. These large public-sector Irrigation Schemes have been constructed and allocated to both entrepreneurs and small-scale settlers. Sixty-seven percent of the irrigation systems in the Northeast are public, as compared to only 6% in the rest of the country, due to the high investments costs in infrastructure caused by aggravated conditions for water access. The Public Schemes of the Northeast, a large share of which grow basic commodities such as cereals, cotton, beans and soybeans rather than fruits and vegetables, generally yield a very low return. This low profitability holds true not only in regard to the net economic return per hectare, but also in regard to the thousands of cubic meters of irrigation water used (Alcoforado de Moraes et al. 2015; FAO 2016).

The Sub-Middle São Francisco River Basin (SM-SFRB) is one of the four hydro-geographic regions into which the basin is divided. This sub-region is the driest among them, contributing to water availability in the overall basin with an inflow of only 4% despite representing 33% of water demands in the entire basin (CBHSF 2004). These demands are primarily composed of Public Irrigation Schemes, domestic water supplies and hydropower. For electricity generation, six reservoirs were built which also generate problems. The two largest have high rates of evaporation and during periods of low inflow to reservoirs only a minimum amount of water can be released, resulting in conflicts with downstream users, who in turn have difficulties to satisfy their own demands (Alcoforado de Moraes et al. 2016).

This conflict between irrigated agriculture and electricity production has the potential to worsen over time. A large water transfer project known as the Transboundary Project of the São Francisco River is being built to deliver water from the Sub-Middle to northern and northeastern areas out of the basin. In parallel with many planned Public Irrigation Schemes in the Northeast, the water for a significant part of these new irrigation projects will either come directly from the São Francisco River or from the channels being constructed. It was estimated that in about three decades, the area under irrigation supplied by water withdrawn from points in the Sub-Middle could increase by more than 10 times its current average (CODEVASF 2006). Being the driest part of the basin, with conflicts already established and projected for the future, the Sub-Middle is a hydrographic region with an indispensable need for water demand management (Alcoforado de Moraes et al. 2011).

Brazilian agriculture is strongly influenced by the global market, as for instance, 31% of the national fruit production is exported (http://www.brazilianfruit.org.br/Pbr/Brasil/Brasil.asp) and from the sugarcane produced - half is used for producing sugar and another half ethanol - about three quarters of Brazilian sugar is exported while 15-20% of the ethanol. Two thirds of the latter are going to the major ethanol export market in the US, which is anticipated to grow in the future as a result of biofuel policies and blending mandates imposed by the Renewable Fuel Standard (RFS) (Carneiro et al. 2014; EPA 2010). The SFRB is one of the main fruit producing regions in Brazil and the cultivation of sugarcane under irrigation there has expanded greatly and under climate change scenarios is expected to expand (Assad et al. 2008). As agricultural production and resulting land use patterns are so closely intertwined with international export markets, we take land use patterns simulated with a global model as our starting point.

The regionalized version of the global agro-economic land and water use model MAgPIE (Model of Agricultural Production and its Impact on the Environment) (Biewald et al. 2014; Lotze-Campen et al. 2008; Popp et al. 2014; Schmitz et al. 2012) was adapted to the SFRB to simulate changes in agricultural production of corn and sugarcane in the SFRB in the context of global drivers. Research findings suggest that in most of the Public Irrigation Schemes in the SM-SFRB users' willingness to pay (WTP) for water is generally greater or at least equal to the water prices currently charged for agricultural use (Silva et al. 2015). Although the irrigated agricultural sector is responsible for most of the water usage in the basin, it contributes only 11% of the amount charged (ANA, 2012) thus indicating that prices paid by the agricultural sector are too low.

In the study at hand we therefore focus on estimating economic values of water for a baseline year (2006) along with future projections for the year 2035. This enables us to determine the user's marginal water benefits, or willingness to pay, for actual and projected Public Irrigation Schemes (PIS) in the SM-SFRB. We use Positive Mathematical Programming (PMP), a methodology well known for successful applications in economic research (Cai et al. 2008; House 1987; Howitt and Gardner 1986; Kasnakoglu and Bauer 1988). Those water values associated with available quantities of water should be supportive of water demand management, as they replace the concept of a fixed water "requirement" with one that captures user behavior and the economic meaning of scarcity.

2.Methods

2.1 Study Area

Our study area is the Sub-Middle (SM) of the São Francisco River Basin. We initially focus on the region with Public Irrigation Schemes located around the *Petrolina* and *Juazeiro* municipalities[1]. This aggregation of PIS, known as *Pólo Petrolina-Juazeiro* (see Figure 1 in Online Resource 1), has increased irrigated agricultural production significantly since its implementation in the 1990s and has become both a major center of fruit production in Brazil and an economic success story (Graziano da Silva 1989; Lima and Miranda 2000; Oliveira et al. 1991; Sampaio and Sampaio 2004). More recently, sugarcane production has also increased in areas with particularly fertile soil; using intensive irrigation and doubling productivity (Alcoforado de Moraes et al. 2016; Amaral et al. 2012).

The second region with aggregated PIS we focus on is the *Complexo de Itaparica*, located around the Itaparica Reservoir, where 10,400 households were resettled from the inundation area during the construction of the reservoir. These PIS have not been considered economically efficient (Figueiredo 2015). According to a recent farm-level study in the region (Hagel et al. 2014), their current production methods are relatively unprofitable for irrigated fruit production thus leading to high economic vulnerability of smallholders.

Estimates used for future total areas by PIS in 2035, as reported by (ANA 2012) and (CODEVASF 2006), were used in this study. The total PIS areas, both current and planned for the future, were considered in our study. These areas as well as municipalities and states where the PIS are located are available in Table 01 of Online Resource 2. According to official data, the PIS areas in both regions considered in 2035 will increase, but keep about the same share as today: 75% of the PIS areas in *Pólo Juazeiro-Petrolina* and 25% in *Complexo de Itaparica*.

In addition to the results of the PIS aggregated by these two main regions, results were obtained for the PIS aggregated by the two municipalities with larger irrigated areas both currently and for the future scenarios. According to the official plans, these are *Petrolina* and *Juazeiro*. These municipalities are in the "*Pólo*" region and in 2006, all PIS areas in the *Petrolina* municipality were 30% of the *Pólo* PIS areas and 24% of the whole Sub-Middle PIS areas. For 2035, these numbers become 39% of the *Pólo* and 29% of the SM PIS. For the municipality *Juazeiro*, its 2006 PIS areas represented 70% (31% in 2035) of the *Pólo* and 58% (22%) of the SM.

2.2. Modelling land use in the SFRB with a global land use model

We used MAgPIE, a global spatially explicit, economic land use model (Biewald et al. 2014; Lotze-Campen et al. 2008) in order to project crop-specific agricultural land use patterns for the SFRB into the future while taking into account the impact of global socio-economic changes, such as population growth, trade liberalization, and changes in overall dietary patterns.

MAgPIE distinguishes between ten world regions for the demand side and uses inputs with a 0.5 degree data resolution on the supply side. With income and population projections as exogenous inputs, required demand is projected into the future. The model simulates time steps of 10 years and uses in each period the optimal land use pattern from the previous period as the initial condition. On the biophysical side, the model is linked to the grid-based dynamic vegetation model LPJmL (Bondeau et al. 2007), which simulates crop yields depending on climatic conditions with a 0.5 degree resolution. We modeled the sixteen most important crop groups. Fruits and vegetables are summarized into one broad group, referred to in the following as 'Other Crops'. In addition to crop yields, LPJmL transfers information on water availability and requirements per cell and crop to MAgPIE, while land availability is data based (Krause et al. 2013). The objective function of MAgPIE is to minimize global costs, which involve production costs for agricultural commodities, technological change costs, land expansion costs, and trade and transport costs. Expansion of cropland is one option to increase the level of production. The expansion involves land-conversion costs for every unit of cropland, which account for the preparation of new land and basic infrastructure investments (Krause et al. 2013). Land conversion costs are based on country-level marginal access costs generated by the Global Timber Model (GTM) (Sohngen 2009).

Although the MagPIE model is based on about sixty thousand spatially explicit cells (about 50x50 km at the equator), due to computational constraints all model inputs on the supply side have to be aggregated to about 1000 clusters for the optimization process (Dietrich et al. 2013). In this study, we use a regionalized version of MAgPIE for the SFRB; where the region of interest is simulated at a higher resolution in order to be able to analyze regional land use patterns.

[1] Municipality is the lowest level of administrative aggregation in Brazil and this is one of the spatial resolution used in Brazilian Agricultural Census (IBGE 2006)

For the adaptation of the global MAgPIE model to the SFRB, the region was simulated based on ten units with similar climatic characteristics. Resulting patterns for pasture land and natural vegetation compare well with the spatially explicit MODIS data (Justice et al. 2002). MAgPIE results for cropland are between the range of area estimates from MIRCA (Portmann et al. 2010) and MODIS (Justice et al. 2002). Comparison of the two land use data sets (MODIS and MIRCA) with the simulation results of MAgPIE for cropland, natural vegetation, and pasture for the year 1995 (in Mha) in the SFRB are available as Online Resource 2 in Table 02.

We base the socioeconomic and climate projections on the SRES A2 scenario (Nakicenovic 2014). In the MAgPIE model, GDP and population projections determine the overall food consumption based on GDP-related dietary habits (per capita calorie consumption and livestock share) and overall population (Bodirsky et al. 2015). Climate change impact on agriculture is taken into account through biophysical data on water availability and yields simulated by the hydrological and vegetation model LPJml. In order to account for the uncertainty connected with modelling climate change, we use results from three different General Circulation Models (GCM)[2]. Results presented in this study are therefore always the median of these three GCMs.

2.3. Description of Scenarios

In our study, we analyze the A2 scenario, a heterogeneous world with rapid population growth, but low economic growth. Governance here is locally oriented with regions being more self-reliant, thus economic growth results in a diversity of income. Climate change is quite rapid, with global warming to be projected between 2.0 and 5.4°C until the end of the century. All relevant socio-economic and biophysical input parameters for the MAgPIE model are listed in Table 3 of Online Resource 2. From the four equally probable SRES scenarios, we have selected A2, because it has the most rapid climate change and serves as an upper bound.

2.4. Deriving economic values of water for the Public Irrigation Schemes in the Sub-Middle São Francisco River Basin

We use Positive Mathematical Programming (PMP) to estimate the economic values of water for Public Irrigation Schemes in the Sub-Middle region of the São Francisco River Basin (SM-SFRB) in a baseline year (2006) and under a scenario with climate change (A2 with CC) for 2035. For the future, we calibrate the irrigated areas of each PIS using simulation results for agricultural land from the global model MAgPIE downscaled to the SM-SFRB, as described in the next section.

As data from farm and PIS levels were not available for all PIS in sufficient quality for the baseline year (CODEVASF 2006), we therefore applied PMP at the PIS level, but rather than using aggregated farm level data, we used municipal level data. This data was obtained from the Brazilian Agricultural Census of 2006 as well as municipal level water data from the Brazilian Environmental Ministry. The latter is also based on 2006 Census information for irrigated areas published as technical coefficients of direct water use by crop, municipality, and month for Brazil (FUNARBE 2011). Therefore, input data for each PIS was deduced from the level of the municipality. Data were only available on the PIS level for two variable costs (see Table 1 for a detailed description).

When water values are estimated on a more aggregate level, it is acceptable to have a smaller set of representative crops available along with inputs grouped by type (Medellín-Azuara 2010). As results from the MAgPIE model in the future were used only for sugarcane[3], we focused on two crop categories: sugarcane and '*other crops*'. The 'other crops' category includes the main crops (fruits and vegetables – F&V) present in the baseline year in each municipality. In the future projection, the current proportions (as in 2006) of *F&V* areas in the municipalities containing PIS were considered (see Online Resource 1, Tables 1 and 2). Sugarcane areas will change according to the MAgPIE results and all additional land aside from that which is freed up will be designated as *other crops* (i.e. fruits and vegetables) area. We considered four input factors in our PMP application: land, labor, water, and supplies (fertilizers, seeds and other input costs) (Howitt et al. 2012; Maneta et al. 2009). All the input data in the baseline year were updated for the future under the A2 scenario with CC as described in Table 1.

<< TABLE 1 >>

The PMP method is able to self-calibrate to the input data - land and water use, production factor requirements and factor and crop prices - in a given reference year. The PMP is based on mathematical programming models that use the information of the marginal values of imposed constraints for calibration (Howitt 1995; Silva et al. 2015).

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[2] The GCMs include MPI ECHAM5, MIUB ECHO-G and UKMO HADCM3.

[3] The projections for 2035 by MAgPIE for irrigated corn production ceases almost totally under A2 scenario .

The formulation of the producers' optimization problem, with all the constraints as proposed by (Howitt 1995) and described by (Silva et al. 2015), allows us to obtain the economic values of water for each irrigated water user (PIS) in a baseline year and in a future year under the A2 scenario with climate change. Using the PMP method also allows us to derive a demand curve for each PIS; running the model with different available quantities of water, noting the shadow value of water each time as described by (Medellín-Azuara 2010).

The PMP problem was calibrated as in (Howitt et al. 2012) for the baseline year and the future year using the global and regional input data as shown in Table 1. All of these input data values and units are available in Online Resource 1 in the tables 01-14.

Medellin-Azuara et al. (2009) described Positive Mathematical Programming (PMP) as a three-step procedure. In the basic formulation, the first step is a linear program providing marginal values that are used in the second step to estimate the parameters for a quadratic cost and production function. These parameters are calibrated to observed values of usage inputs in agricultural production. In the third step, the calibrated production and cost functions are used in a non-linear optimization problem.

Our study uses a constant elasticity of substitution (CES) production function as was used in the study by (Medellín-Azuara 2010). This production function restricts the extent to which one input can substitute another. For the elasticity of substitution for all crops and regions, a similar value (0.5) was adopted for the São Francisco River Basin as was used in another PMP study (Maneta et al. 2009; Torres et al. 2012). This signifies a medium rate of substitution among production factors which can represent the production technology in regions such as the SM-SFRB. For the cost function calibration, the quadratic functional form and the supply elasticity of the cultures of 0.2 were also used as in the referenced papers. In general, the base economic values of water associated with the different supply elasticities are the same.

In order to project the prices of the two crop categories (sugarcane and other crop prices) in the future year, the same growth rates for the production costs associated with the future scenario were used in the first step of the PMP (Linear programming) (see Table 1). In addition, we used a scaling factor by crop and region in the non-linear objective function of the third step of the PMP to simulate demand-induced price changes and to allow for calibration.

2.5 Integrating global drivers

In order to understand how global changes, such as population growth, changes in diet preferences, or climate change impact economic values of water in our study area, we need to integrate information on projected changes in agricultural production into our PMP methodology. As a precondition, we downscaled the results from the regionalized version of MAgPIE in order to obtain irrigated sugarcane areas by municipality and by PIS.

As a first step, the SM-SFRB hydrographic region was matched to the computational simulation units of MAgPIE (see map in Online Resource 2, Figure 1). This resulted in our hydrographic clusters. Secondly, the regional data given by municipalities was adjusted to the same level in order to utilize and compare it to the MAgPIE results.

The best validation results were obtained with the data for annual irrigated area given in (FUNARBE 2011) based on the Census 2005/2006 by municipality (IBGE 2006). MAgPIE simulations for the three hydrographic clusters in 2005 under the A2 scenario with climate change (SM-SFRB region) resulted in 77,100 hectares of sugarcane, which compared reasonably well to the 100,464 hectares used by FUNARBE (2011). After that, it was necessary to distribute the validated irrigated sugarcane areas from MAgPIE in 2005 among the municipalities.

According to the 2006 Census, cultivated sugarcane area was highly concentrated in one municipality (*Juazeiro*) in the SM-SFRB. This can be attributed to the soil quality, which was not included in the MAgPIE model set-up. Data from (SUDENE 1979) in Brazil shows that sugarcane is currently cultivated on most of the Northeast along the coast, in areas with two specific soil types classified by USDA Soil Taxonomy[4] as: Ultisols and Oxisols. However, in *Juazeiro* the crop has been cultivated in very productive soil (Vertisols) with very intensive irrigation, resulting in a doubling of productivity (Amaral et al. 2012; Silva et al. 1993). After bias-correcting the simulation results with the information on the soil data, we were able to validate the MAgPIE sugarcane area in 2005 on the municipal level (see Online Resource 2, Figure 2).

3.Results

3.1. Future Land Use at SFRB

Modelling results with MAgPIE show that agricultural areas more than double from 2005-2035 (from 4 to 9 Millions of ha). Irrigated sugarcane is produced on an additional 2.5 Mha in 2035, as compared to the production in 2005. Irrigated corn

[4] https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/class/taxonomy/

production decreases from 1.2 to 0.8 Mha. The reason for this is the comparatively good conditions for irrigated production of sugarcane. Agricultural production of corn on the other hand is shifted to other regions of Latin America. In the relatively short time frame considered in our paper, climatic conditions in the SFRB regions are projected to become relatively wetter *(Inter-Sectoral Impact Model Intercomparison Project ISI-MIP, www.isimip.org)*. Additionally, as climatic conditions in other world regions deteriorate, pressure on agricultural production for exports from Latin America will increase.

A study by Assad et al. (2008) found that a huge expansion of suitable irrigated sugarcane areas in the SFRB, and in Brazil as a whole, will occur under climate change scenarios (A2 and B2) and will require more water than in traditional areas. According to that study, the crop will be the only one in the country, which will not have its suitable production areas reduced as a result of higher temperatures.

Based on the validation criteria (geographical area and type of soils) explained in the last section, MAgPIE sugarcane areas for 2035 were distributed among municipalities, as well as existing and planned Public Irrigation Schemes. The agricultural land considered for sugarcane production, in the existing and planned PIS studied, represents around 65% of the total sugarcane area estimated by MAgPIE for 2035 in the SM-SFRB (The distribution obtained for 2035 among municipalities and PIS are available in Online Resource 2, Figure 3) .

3.2. The economic values of water for the Public Irrigation Schemes in the baseline year and under the future scenario

The economic values of water for the baseline year and under the future scenario were obtained for each PIS located in the Sub-Middle region (the water values by PIS are available in Online Resource 1, Table 15). Subsequently, we aggregated those by region and municipality using a weighted average. Depending on the percentage of water used by one PIS in each region or municipality, its water value would be more or less important in the weighted average water value of the region or municipality (the weights depend on the amount of water used by the PIS as related to the total amount of water used in the region or municipality). The same process was followed in order to obtain the weighted average water unit costs[5] by region or municipality (water unit costs by PIS are also available in Online Resource 1, Table 15*).*

All monetary values[6] are presented in Table 2 in Brazilian (BRL) Reais (R$) for the year of 2006. In that year, the exchange rate was 2.96 Reais to the US Dollar. The projection used for updating monetary values in the future (2035) was the growth rate of production costs used in MAgPIE, therefore the results reflect the real change (rather than the nominal one) of the values in the index year (2006).

<< TABLE 2 >>

The main variables which influenced the results for economic values of water presented in Table 2 in the baseline year and under the future scenario, were also obtained by PIS and aggregated by region or municipality using a weighted average (see Figure 1). As these variables are all measured per hectare, the weights in this context depend on the area used by the PIS in relation to the total amount of land in the region or municipality. Based on the land use pattern in the two crop categories by region and municipality (A), a weighted average of yields for all the crops grown (B), of water requirements[7] per hectare (C), and of water costs per hectare (D) were obtained and are presented in Figure 1. The water cost per hectare is obtained by combining water requirements and water unit costs.

<< FIGURE 1 >>

Regional and municipal weighted average water value in the baseline year

The economic value of water for the baseline year averages R$ 682/1000 m^3 for the whole set of PIS. This amount is lower than the average water value of PIS in the *Pólo* region, but is much higher than the water value of PIS in the *Complexo de Itaparica* region (Table 2). Thus, among regions, the lowest average water value was found in *Complexo de Itaparica*. This can be explained by having the lowest average yields (Figure 1 (B)) and production factor costs as a whole which are not significantly lower than the ones at *Pólo*. In fact, labor costs per hectare in the "*Complexo*" region are very low (R$283/ha) compared to the *Pólo* region (R$ 1,720/ha), as well as to the rest of the Sub-Middle (R$1,490/ha). However, the share of the

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[5] The average variable cost of water (see Table1)

[6] All the tables in Online Resource 1 presenting monetary values are also in Brazilian Reais (R$) for the same index year(2006)

[7] A Leontief coefficient (see Table1)

total cost of production used for labor in *Complexo de Itaparica* is also very low (3%). Meanwhile, water costs per hectare in the *Complexo* region represent almost half the amount of those in the *Pólo* region (see Figure 1 (D)). This is also the case with supply costs (R$ 1,535 per ha in *Complexo* and R$3,636 per ha in *Pólo*), which constitute only 16% and 20% of the total production factor costs, respectively. On the other hand, land costs constitute 60% of the production factor costs in that region and are not significantly less (R$ 4,536 per hectare) than the ones at *Pólo* (R$ 6,313 per ha) or in the SM as a whole (R$6,021 per hectare).

If we look at the weighted average water value by municipality, the value for the *Juazeiro´s* PIS is much higher (R$987/1,000m^3) than the one for the *Petrolina´s* PIS (R$199/ 1,000m^3). This can be explained by the higher crop yields in *Juazeiro* (see Figure 1 (B)). Moreover, the land costs for these two municipalities are an important share of the total production costs (37.8% for *Petrolina* and 48.9% for *Juazeiro*) and are higher for *Petrolina* (R$7,489 /ha) than for *Juazeiro* (R$ 5,820/ha). The labor and supply unit costs are very similar for the two municipalities, but as *Petrolina* has higher Leontief coefficients for both inputs (*Petrolina* hires 1.34 worker per ha and *Juazeiro* 0.57 worker per ha) and spends R$ 6,510 per ha on supplies (*Juazeiro* uses R$2,431 per ha), total costs of these factors per hectare are also higher for *Petrolina* municipality. The weighted average water requirements in the two municipalities are similar (Figure 1 (C)). But the unit water costs are higher for *Petrolina* (R$118/1000m^3) than for *Juazeiro* (R$86/1000m^3), thus resulting in higher water costs per hectare for the *Petrolina* municipality (Figure 1 (D)) and decreasing its marginal benefits (water values) as compared to *Juazeiro*.

Projected weighted average water values for 2035 by region

In the future scenario (see Table 2), including climate change, the weighted average water value increases to R$ 902/1,000 m^3 over the whole set of PIS. This increasing is very similar to the value in the *Pólo* region (from R$746 in the baseline year to R$1,004) in 2035, which will use around 85% of the total water used at SM in the future. The increasing of average water value for "*Complexo de Itaparica*" is even higher, although its water value keeps being the lowest among the regions in the future.

The average yields are lower for *All PIS and* the *Pólo* region in the future (see Figure 1 (B)). These future weighted average yields by region not only reflect the land use pattern projections provided by MAgPIE and calibrated by PMP for the future (Figure 1 (A)), but also reflect the yields of the new irrigated areas planned to be incorporated by 2035.

If we look at the percentage of irrigated areas (see Figure 1 (A)) by crop and region, one can note that the percentage of sugarcane in the future scenario is lower (sugarcane has higher yields than fruit and vegetables), as compared to the baseline year for the *Pólo* region and as a result for the SM region as a whole.

Moreover, the new areas planned are primarily to be established in the *Pólo* region, which is already the main region with PIS in the Sub-Middle region as a whole. Currently, *Pólo* and *Complexo de Itaparica* have 75% and 25% of the PIS areas in the SM. Of the total new areas planned to be established by 2035 in existing and future PIS, 71% will be in the *Pólo* region, and 29% will be in *Complexo de Itaparica*. Generally in a given region, areas with higher yields are used first, it is therefore expected that these expansions should also contribute to the decreasing average yields in *Pólo*.

Regardless, as the average prices are higher in the future for the two categories of crops, and due to the lower annual weighted average water requirements compared to the baseline year (see Figure 1 (C)) not having a significant impact on the water costs per hectare by region, average water values will increase for the the *Pólo* and *All PIS* regions.

Also in the case of the *Complexo* region, the average water value increases as the average prices are higher and yields are not significantly different in the future (same land use pattern). Meanwhile, even though the water unit costs (see Table 2) increase for this region, the resulting average water costs per hectare do not increase (Figure 1 (D)). This might be explained by a significant reduction in the average water requirements (Figure 1(C)) in the future scenario. The reduction of the average water requirements at *Complexo*, even without changes in its land use pattern (Figure 1 (A)), can be interpreted as resulting from the new PIS projected for that region. Large PIS are planned (see Online Resource 2, Table 01) in the municipality of Gloria, which presents Leontief coefficients for water below the current average (see Online Resource 1, Table 14*).*

The decreasing percentage of irrigated sugarcane area in *Pólo*, and as a result the entire SM region (Figure 1 (A)), also leads to lower annual weighted average water requirements compared to the baseline year but does not lead to lower water costs per hectare (Figure 1 (D): This is most likely due to the higher water unit costs for *Pólo*. One can note that water costs per hectare (water requirements multiplied by water unit costs) presented in (Figure 1 (D)) are higher in the future for the *Pólo* region as well as for the SM as a whole, but not for the *Complexo* region. That is why the increasing of water values in *Complexo* are higher than in *Pólo* and in the SM region.

Moreover, land costs, which will continue to make up an important share of total production costs (50% for *Pólo* and 52% for SM as a whole) in the future, will also increase for all regions. This increasing will be particularly notable in *Pólo* (from R$ 6,313 per ha in the baseline year to R$ 11,021 per ha in 2035).

Projected weighted average water values for 2035 by municipality

The weighted average water value for the *Juazeiro* municipality continues to be much higher (R$1,990/1,000m^3) than that of the *Petrolina* (R$297/1,000m^3) and both of them increased relative to the baseline year. However, it is important to note that the increase is much higher for *Juazeiro*. In both the baseline year (2006) and the future scenario, *Juazeiro* produces sugarcane on about half of its irrigated area (53% in 2006 and 57% in the future) and produced high-return fruits on the other half. *Petrolina* produces fruit, primarily for export, on almost its entire irrigated area with high returns.

Due to the increasing sugarcane areas in *Juazeiro* as compared to the baseline year, this is the only region/municipality that also shows an increase in its weighted average yields (see Figure 1 (B)). This results from higher yields of sugarcane as compared to fruits and vegetables. The higher percentage of sugarcane also explains the increase in the average water requirements (see Figure 1 (C)) for *Juazeiro* related to the baseline year and a resulting increase in the water costs per hectare.

However, it is important to highlight that even though the PIS at the municipality of *Juazeiro* has the highest increase in average water requirements in the future and will have almost the same average water requirements as *Petrolina* in 2035, its water costs per hectare are lower than the ones in *Petrolina* (see Figure 1 (D)). One can note that water unit costs in *Juazeiro* are lower than in *Petrolina* (see Table 2).

In the municipality of *Petrolina*, the average prices of the crops produced are higher in the baseline year as well as in the future scenario than the average prices in *Juazeiro*. This is due to *Petrolina´*s production of fruits which generate high returns and are mainly for export (For average prices see Online Resource 1, Table 13*)*.

Nevertheless, the average water value results remain much higher in *Juazeiro*. This is probably due to high yields in *Juazeiro* along with low water costs per hectare even given high annual water requirements. The share of total water costs in total production factor costs in *Juazeiro* is 18 % in the baseline year, and barely changes to 17.5% in the future under the A2 scenario with climate change. Total water costs in *Petrolina* represent 17% of the total production cost in the baseline year and 13.3% in the future. [8]

Also for the three regions studied (SM, *Pólo* and *Complexo*), the total water costs represented did not constitute a large share of the total cost of production (17.5%, 17.6 % and 16.2% respectively) in 2006. In the future, this share may decrease slightly to 12%, 11.9%, and 12.2%. As is the case in the MAgPIE model set-up, improvements in irrigation efficiencies were not taken into account. The lower proportion of water costs in the total production factor costs, under the future scenario for all regions, can be explained by the overall crop combination estimated by MAgPIE. On average in each of the regions (SM, *Pólo* and *Complexo*), this requires less water per hectare relative to the baseline year (see Figure 1 (C)). Additionally, in the São Francisco River Basin, water prices - part of the water unit costs - for irrigated agriculture are usually low (Alcoforado de Moraes et al. 2016) and Brazilian government subsidizes generally cover many of the other components of water costs in Public Irrigation Schemes.

The water prices paid to the water authority are expected to increase over time, with the subsidies also expected to change, as water conflicts worsen, but this was not taken into account in our study because of the lack of information about how these prices and subsidies will be adjusted. For this reason, the estimates of the economic values of water presented in Table 2 should be considered as keeping current water policies.

4. Discussion and Conclusions

Local water scarcity can be alleviated through imports of agricultural goods or intensified through exports, especially of crops with high water requirements (Biewald et al. 2014), such as sugarcane. In order to avoid enhanced water scarcity due to exportation, the price of irrigation water should reflect its scarcity. The integration of a global model (MAgPIE) with a local model to identify the economic values of water show the influence of global forces on decisions concerning irrigation and the use of local land and water. These values are essential for setting water allocation and management policy (Medellín-Azuara 2010) that foster sustainable development in the region and not intensify already existing conflicts. Hydro-economic models

[8] The total land costs in *Petrolina* constitute 42.% and the total supply (capital) costs are 32% of the total production costs in the future.

(Harou et al. 2009) require estimates of water values for all sectors including agriculture in the form of demand curves. These curves are a means of integrating economic behavior into these mathematical models, designed to study the economic effect of different water policies such as water pricing.

Global models that take into account biophysical and economic factors to analyze a specific country land use have also been widely used. Biewald et al. (2015) addresses the production of cereals and oilseeds in Finland using the MAgPIE model. The advantage of a global model is the possibility of verifying the effect of changes in the international scene at the local level. Regionalized versions of the MAgPIE model to the São Francisco river basin were described by Beck (2013) and Kölling (2014). Both have studied the impacts of climate change on agricultural production in the river basin. As previous versions of MAgPIE had stricted global regions and Beck (2013)'s work focused on a specific Brazilian river basin the validation results were not satisfactory.

Kölling (2014) on the other hand, points to direct influence of climate change in sugarcane irrigated cultivation areas, which alongside fodder crops will dominate the Brazilian agricultural growing areas in all future scenarios analyzed (from a global environmentally concerned to a more regionalized free market scenario). The land use changes projected by Kölling (2014) under the A2 scenario with CC were downscaled to the main PIS in the SM-SFRB and could satisfactorily be calibrated by the PMP methodology. Combining regional data for a baseline year with the estimates and also the growth rates considered in the global model, it was possible to estimate the economic values of water for each PIS in the main regions and municipalities of the SM-SFRB in a reference year (2006) and also in a future scenario (2035, A2 with CC).

In the São Francisco River Basin, most of the Irrigation Schemes are public. These Schemes have primarily been financed by the government and still depend on water supplies developed, and in many cases payed for using government funds. Moreover, official biophysical data (http://www.global-warming-forecasts.com/water-supply-shortage-water-scarcity-climate.php) shows that, until 2035, no serious water shortage is to be expected in this area. Therefore, the SFRB has been considered the last frontier of cheap land and “abundant” water for the production of irrigated sugarcane in Brazil. This apparent abundance is due to low water prices for agricultural users as well as infrastructure investments with high public contributions (Alcoforado de Moraes et al. 2016). It is therefore essential to obtain economic values of water, which take future scenarios of local and global market and climate conditions into account, as has been done in this study.

The allocation of sugarcane and fruit crops projected with climate change by the global model showed an impact on the average crop yields and on the water costs in the main PIS resulting in changes in the water values. The weighted average economic values of water for all regions and municipalities in the baseline year are much higher than the water prices established for agricultural use in the SFRB at R$10/1000m^3 since 2006 (Alcoforado de Moraes et al. 2016). Additionally, they are still higher than the average water unit costs associated with the same region (Table 2). In the future, these water values will be higher in all the schemes. The highest water values currently and in the future, were identified in regions or municipalities with a significant proportion of area growing irrigated sugarcane (*Juazeiro* municipality, *Pólo* and SM regions). The highest weighted average water value among all regions and municipalities occurs in the *Juazeiro* municipality (R$1,990/1000m^3). These high economic values of water associated with irrigated sugarcane production should continue to provide particular economic incentives to the PIS for the expansion of irrigated sugarcane areas; along with potentially increasing export demand for biofuels from other less favorable world regions.

The design and application of adequate water allocation instruments (such as water rights or water pricing) can change water values, as they provide incentives to the users (for instance by changing the crop mix or changing irrigation technologies). Being aware of the current water values of each user in a baseline year and in a projected future, decision makers should improve water allocation policies. These values in the form of a demand curve were already used in a hydro-economic model developed for SM-SFRB in different scenarios by Souza da Silva and Alcoforado de Moraes (2018 (under review)). This region-specific information should be immensely helpful in supporting water policy design which may avoid conflicts and unsustainable development in the future.

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FIGURES

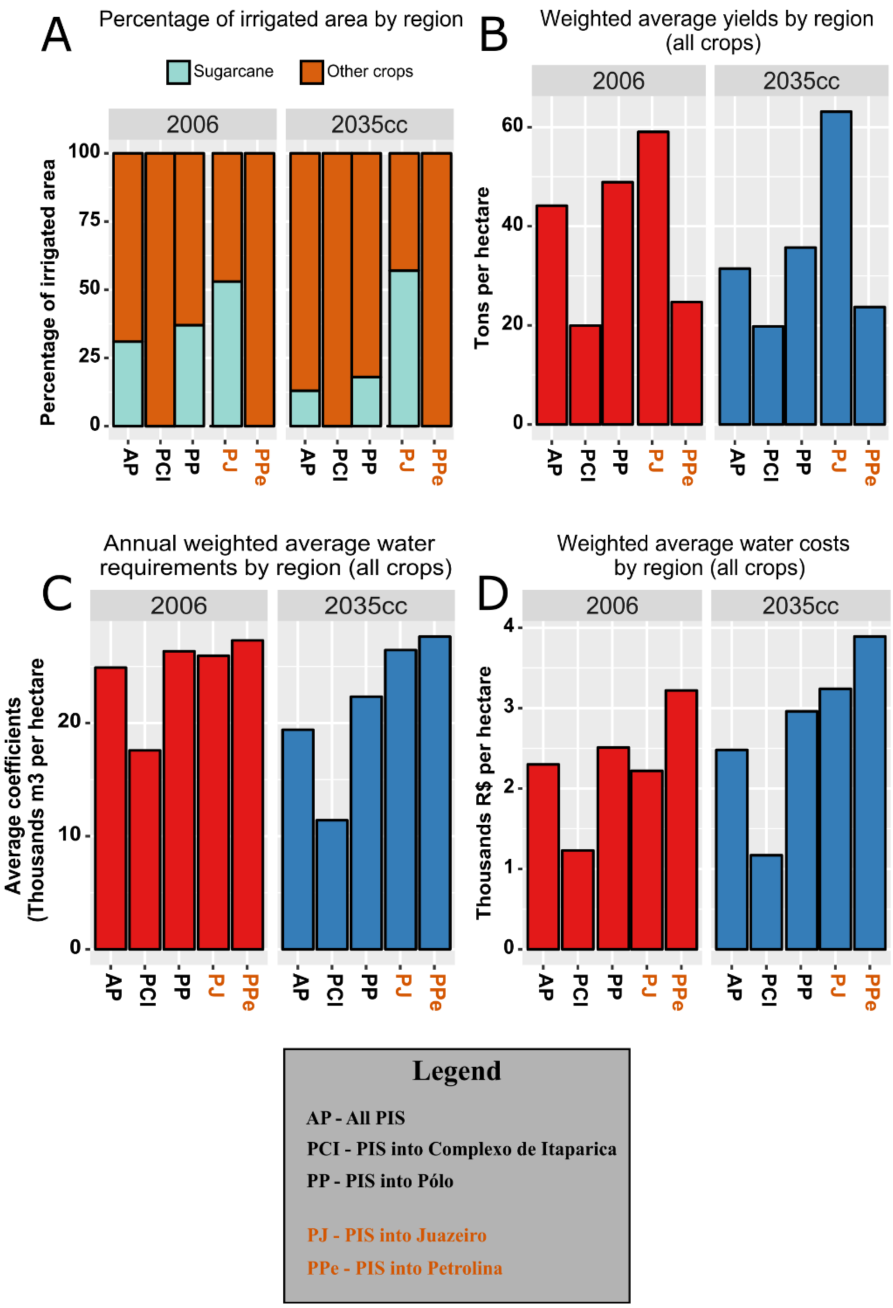


Figure 1 - Percentage of irrigated area by crop, weighted average yields (all crops), annual weighted average water requirements (all crops) and weighted water costs (all crops) by regions (black) and municipalities(red) in the baseline year and under the A2 scenario with Climate Change.

Tables

Table 1 - Sources and methodologies for deriving input data for the base year and future projections for the year 2035 by Public Irrigation Scheme

Input Data		**Baseline Year (2006)**	**A2 scenario with Climate Change (2035)**
Total Irrigated Area		(CODEVASF 2006)	Based on Brazilian Government Plans reported by (ANA 2011)
Irrigated Sugarcane area		Census 2006 ((IBGE 2006)IBGE) by municipality associated proportionally to the PIS size	Downscaled from MAgPIE regionalized results with CC using distribution criteria validated in the baseline year
Other Crops irrigated area		Census 2006 (IBGE 2006) with the most representative crops other than sugarcane by municipality associated proportionally to the PIS size	Total irrigated area excluding sugarcane downscaled from MAgPIE with CC (proportions with land use by type of crops were the same as in the baseline year)
Sugarcane Yields		Annual Average yield between 2002 and 2012, obtained using the Municipal Agricultural Production [(PAM 2012)]. by municipality[9]	Projections using climate change simulations for sugarcane yield simulated by MagPIE (2005 until 2035) by hydrogeographic cluster*. Yields grow according to endogenous technical change simulations,
Other Crops Yields		Weighted average (proportions with the land use by type of crop) of the annual average yields of each crop ((PAM 2012)) by municipality*	Projections using climate change simulations for other crops yield simulated by MagPIE (2005 until 2035) by hydrogeographic cluster*. Yields grow according to endogenous technical change simulations.
Leontieff coefficients given by the total factor usage to land.	Water	Water requirements or demand for irrigated agriculture by crop[10] and municipality* (FUNARBE 2011)	Water requirements (2006) updated to 2035 using changes in temperature and precipitation provided by HADCM3 model(Carneiro 2014)
	Labor	Number of workers per hectare by municipality* and for the two crop categories discusses ((IBGE 2006)) *Using that labor coefficient and the crop yields in the baseline year (2006) we also estimated the number of employees per tons produced in 2006 in order to update this coefficient for the scenario w CC .*	Projections based on the number of employees per tons produced in 2006 combined with the two crop categories yields with CC by municipality*
	Supplies	The values spent on factors per hectare by municipality* and for the two crop categories (IBGE 2006) *Using that supplies coefficient and the crop yields in the baseline year (2006) we also*	Projections based on the values of supply requirements spent per tons produced in 2006 combined with the two crop categories yields with CC by municipality* ..

[9] *The association between PIS and municipality as well as a hydrographic cluster is direct. It means that the PIS use the same number of the municipality or the hydrographic cluster it is located.

[10] Water requirements were obtained by crop and municipality by (FUNARBE 2011). For *Other Crops* category we used an annual weighted average (proportions with the land use by type of crop) of the annual water requirements of each crop.

		estimated the values of supplies requirement per tons *in 2006 in order to update this coefficient for the scenario w CC* .	
Sugarcane Prices		Average annual prices for the years 2002 to 2012 using total value of annual production and the total amount produced by crop and municipality*(PAM 2012) .	Projections based on the growth rate of production costs for sugarcane by MAgPIE with CC between 2005 and 2035 (same for all hydrographic clusters*)
Other Crops Prices		Weighted average (proportions with the land use by type of crop from FUNARBE) of the average annual prices during the years 2002 to 2012 using total value of annual production and the total amount produced by crop and municipality*(PAM 2012)	Projections based on the growth rate of production costs for *other crops* by MAgPIE with CC between 2005 and 2035. (same for all hydrographic clusters*)
Average Variable Costs.	Water	Based on costs for water provision charged in each PIS. (CODEVASF 2006)[11]	Projections based on the growth rate of the production costs for the two crop categories given by MAgPIE with CC[12] .for all hydrographic clusters*.
	Labor	Based on expense information and number of workers[13] by municipality* .	Projections based on the growth rate of the production costs for the two crop categories given by MAgPIE with CC[14] for all hydrographic clusters*.
	Supplies	The value for the two categories of crops was a capital interest rate (1.06) for the region (all PIS) in the baseline year (Figueiredo 2015)	Projections based on the growth rate of the production costs for the two crop categories given by MAgPIE w CC[15] for all hydrographic clusters*.
	Land	`Based on leasing expenses and total area leased (Census 2006[16]) for all crops by municipality*[17]. .	Projections based on the average growth rate for the two crop categories costs given by MagPIE with CC..

.

[11] Still nowadays for many farmers in Public Irrigation Schemes in São Francisco River Basin that had been established as compensation for compulsory relocation, water and energy for pumping are still free. In fact, this charge is applied in a very few PIS currently and in order to represent the water costs in the PIS which were not yet charged for the provision of raw water , but have these costs, we used average values of the existing charges in the PIS related to their size.

[12] With CC this value was discounted with the changes in the water requirements per hectare due to climate changes .

[13] These numbers were found the same for all crops.

[14] With CC this value was discounted with the changes in the number of workers per hectare due to the crop yield changes w CC.

[15] With CC this value was discounted with the changes in the value of supplies requirement per hectare due to the crop yield changes w CC

[16] For some municipalities there were no reasonable data and we need to use the average values of the neighboring municipalities. The values of leasing expenses and area leased for the municipality of Rodelas were not found in the Census 2006 data. Also, in the municipalities of Gloria and Casa Nova, there were very low values for area leased and very high values for leasing expenses. . Therefore we did not include the values of Census for these municipalities and used the values of the nearest municipality as proxies for them.. In the case of Rodelas and Gloria, we adopted the cost of land for Petrolândia; and in the case of Casa Nova, we used the average values of the neighboring municipalities of *Petrolina* and *Juazeiro*.

[17] There was also a variable land cost charged to farmers in each PIS by CODEVASF named K1, which was also included in the existing PIS. *To determine an estimate of this values charged to farmers for the new PIS, the existing PIS current values were related to size and projected for the new ones.*

Table 2 - Weighted average water values obtained and water unit costs in Brazilian currency (BRL - Reais) per thousand of cubic meters by region or municipalities in the baseline year (2006) and in 2035 under A2 scenario with climate change .

	Baseline Year (2006)		Future Year (2035) A2 Scenario with Climate Change	
	Water Unit Costs (BRL/1,000 m^3)	Economic values of water (BRL/1,000m^3)	Water Unit Costs (BRL/1,000 m^3)	Economic values of water (BRL/1,000m^3)
All *Public Irrigation Schemes* (PIS)	93	682	128	902
PIS into *Pólo*	95	746	133	1,004
PIS into *Complexo de Itaparica*	70	195	102	358
PIS into *Petrolina*	118	199	141	297
PIS into *Juazeiro*	86	987	123	1,990

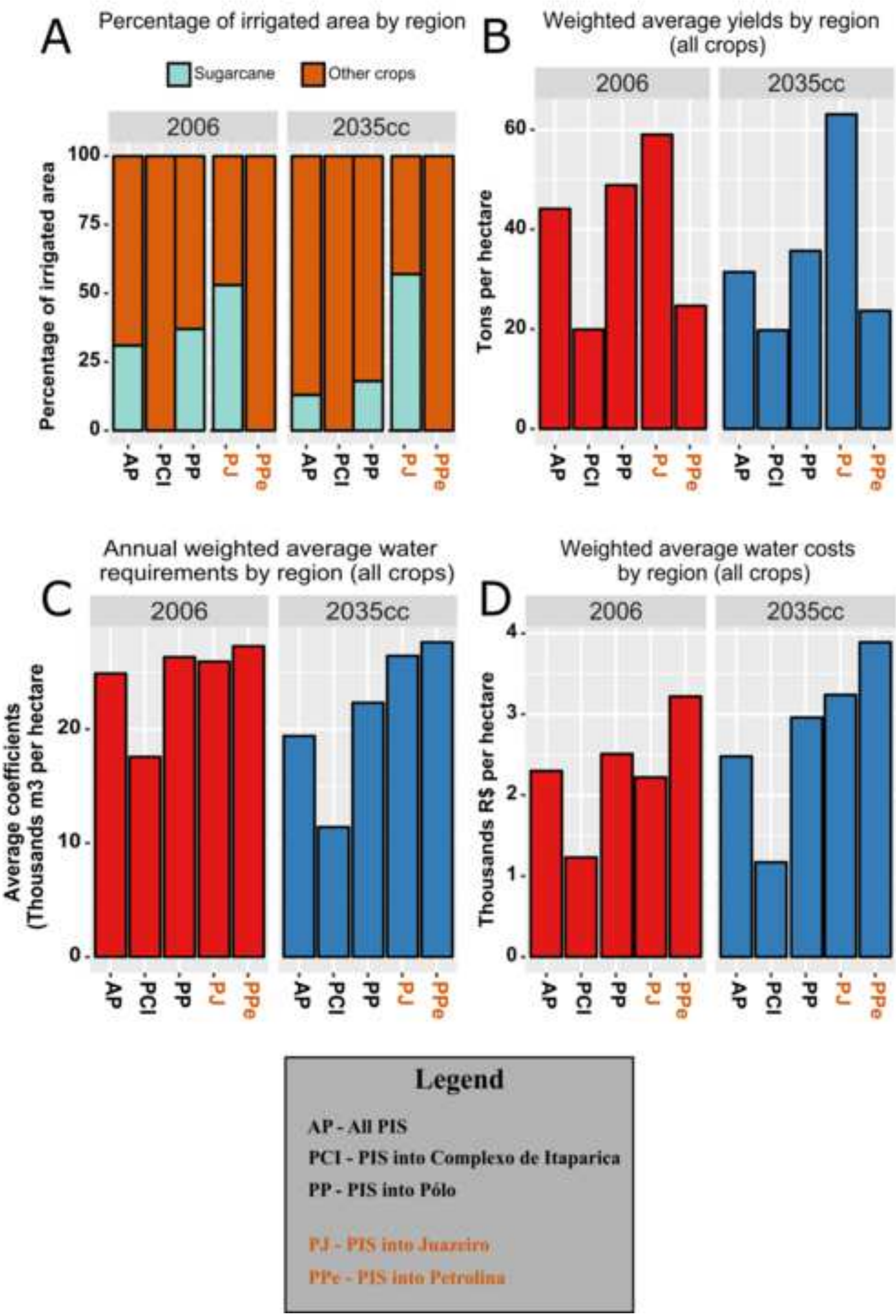
Comment	Responses
Thanks to the editors for the new comments and suggestions, that I consider improved a lot this final manuscript. Please see below a list of changes/ explanations related to the general and the specific points raised by the editors.	
General Points	
I strongly suggest to separate results and discussion. Currently there is little discussion and almost no placing of the results in the wider literature.	I have made that. Now the Results section is only description of our results and the last section became Discussion and Conclusions. Other references in the literature were included.
Shorten the conclusion to make a few, clear points	I made that. The section Discussion and Conclusions was remade and shorten in order to clarify the main conclusion points. There were included new paragraphs there.
The electronic supplementary material needs a title page	I put it.
The abstract could be improved. Currently half of it is introduction and only a few sentences refer to the results.	I have rewritten the abstract in order to make it clearer and more objective.
Please make sure the headings and subheadings do not contain any acronyms and all acronyms used in figure/table captions and are explained within the caption/figure	OK. I revised all tables and figures in the manuscript and also in the Online Resources 1 and 2 .
Guest Editor	
The authors responded to each point of the last review. In order to finalize the manuscript, the authors should now focus on: providing an attractive abstract that gives clear indications of results and relevance of the study, strengthening the comparison of own results with the wider literature in the discussion, including consolidating the conclusions to major messages	The abstract was rewritten as well as the last section - discussions and conclusions - in order to attend these editor´s suggestions.
Line 26: there "could" be more water.. the different scenarios are finally not fully conclusive, you just have chosen one that shows more water in the future	The abstract was rewritten. There is no more that sentence.
Line 28: the abstract mentions the River Basin Committee, although this one is I think not mentioned in the manuscript . the abstract lacks a final conclusion, an overarching message: why should somebody from elsewhere in the world be interested in reading a paper with very local results – what is the message that could be interesting for scientists concerned with issues related to regional environmental change?	The abstract was rewritten. There is no more the mention to River Basin Comitee and I´ve tried to clarify the main message. I hope I could make it .
Line 46 and 269: red comma should be black	OK
Line 70: exchange energy by electricity	OK
Line 74/75: you probably mean ..supplied by the Sao Francisco River..? not by the Sub-Middle. Or it is meant …area under irrigation within the Sub-Middle	I meant : "the area under irrigation supplied by water withdrawn from points in the Sub-Middle could increase by more than 10 times its current average" . It means that the water will be withdrawn from the region (SM) and will compete with other uses directly there. The area under irrigation supplied is not only for areas within the SM but also for deliveries external to the basin as for the PISF. Please see if the new sentence became more understandable.

Line 75: basin in lower case	OK
Line 77: the full stop should be placed after the parenthesis and not before it	OK
Line 80/81: of the latter "are" going	OK
Line 203: you probably mean factor prices, then remove the comma after factor and add an "and" before factor	OK
Line 207/208: position of parentheses: ..as proposed by Howitt (1995) and described by Silva et al. (2015). Similar: line 211, 213, 223 (while 226 is correct) – check in the whole manuscript, I will not take note anymore in the following	OK. Those were corrected and others identified and corrected.
Line 257ff: there is little discussion in the following. I would call the chapter just Results. Discussion would mean comparison with literature, what is almost not the case here (only about two references used)	OK! The chapter is now entitled as Results only.
Line 260: show not shows	OK
Line 300: delete the full stop before were	OK
Line 307: missing superscript. Also: 321, 328, 380/1, 435	OK
Line 309: full stop after and not before: (Table2). Similar: 411, 436	OK
Line 422: I would call this chapter "Discussion and conclusions" …....and you should now come back to your initial hypothesis which stated "that prices paid by the agricultural sector are too low". You need a clear discussion of your results in regard to your objectives of the study and the mission of the journal. What is the relevance of your study to the international readers of Regional Environmental Change? This involves interpretation and comparison of your results with relevant international literature. You may shift parts of the previous chapter to this here. Using literature (in particular from other studies, not only your own) is mandatory.	Thanks! I have changed this chapter´s title and content in order to clarify the major message and the relevance of the paper . I have also included other references related to integrating models of global to local scale and also hydro-economic modelling . However, comparison of water values (our results) are not so easy to make, because of the nature of these values . They are very specific-region information.
Line 424: why "potential" integration?	I removed "potential"!
Line 424: why "can show"? did you show or not?	I removed "can".
Line 430: write F&V in full	In bold? OK
Table 1: average variable costs – why did land get an extra section, separated from water, labor and supplies?	My mistake! I removed it! Thanks.
Tables 1 and 2: table titles always above	OK
Supplementary material, Online Resources 1 and 2	
Please check the author guidelines – the online material still lacks all title page information. It is important that you provide the whole material in its final format and correctness since:"Electronic supplementary material will be published as received from the author without any conversion, editing, or reformatting.	OK
Tables: the table title should always be given above the table (not below as is only the case in figures)	OK
Tables 1 and 2: unclear how you differentiate among "crops"-Tab 1 and "other crops"-Tab 2, since both tables show finally the same crops	I changed the table title: Table 1:-*Current (2006) proportions of crop areas (sugarcane and other crops) in the municipalities containing PIS considered in our study (FUNARBE).* Table 2: I

	added the year (2006) along with the word *Current:*
Table 2: ..current proportions considered in 2035..? unclear what you mean – what is “current” here? Values from 2006 as in Table 1? Probably you need to rephrase both table captions in order to be very clear	Yes, for 2035 only for the Other Crops we considered the same proportions currently (2006) in the existing and new areas. Only for sugarcane in the future we considered the land use areas previewed by MagPIE. Please see the new table captions for Table 1 and 2.
Table 5ff: unclear why you have chosen that sequence of rows. It looks arbitrary/unordered. Please, provide clearly ordered tables.	OK.
Table 8: write units in English	*OK*
Appendix 2	
Table 2: there is a track change mark	Sorry! I couldn´t find that.
Table 3: what did you use finally, own calculations or the indicated reference?	Own calculations using the methodology described in Bodirsky et al. (2015). I put there in order to clarify
Figure 2: which color is finally the soil class adequate for sugarcane? All three?	YES! All three are adequate….as written in the legend.

Figure

[Click here to download Figure Fig2NewNormalizedValues.png]



The impact of global changes on economic values of water for Public Irrigation Schemes at the São Francisco River Basin in Brazil. *Regional Environmental Change*. Alcoforado de Moraes*, MMG., Biewald, A., Carneiro, ACG.,da Silva, G.N.S., Popp, A., Lotze-Campen, H.*UFPE, marcia.alcoforado@ufpe.br.

Online Resource 1

Figures

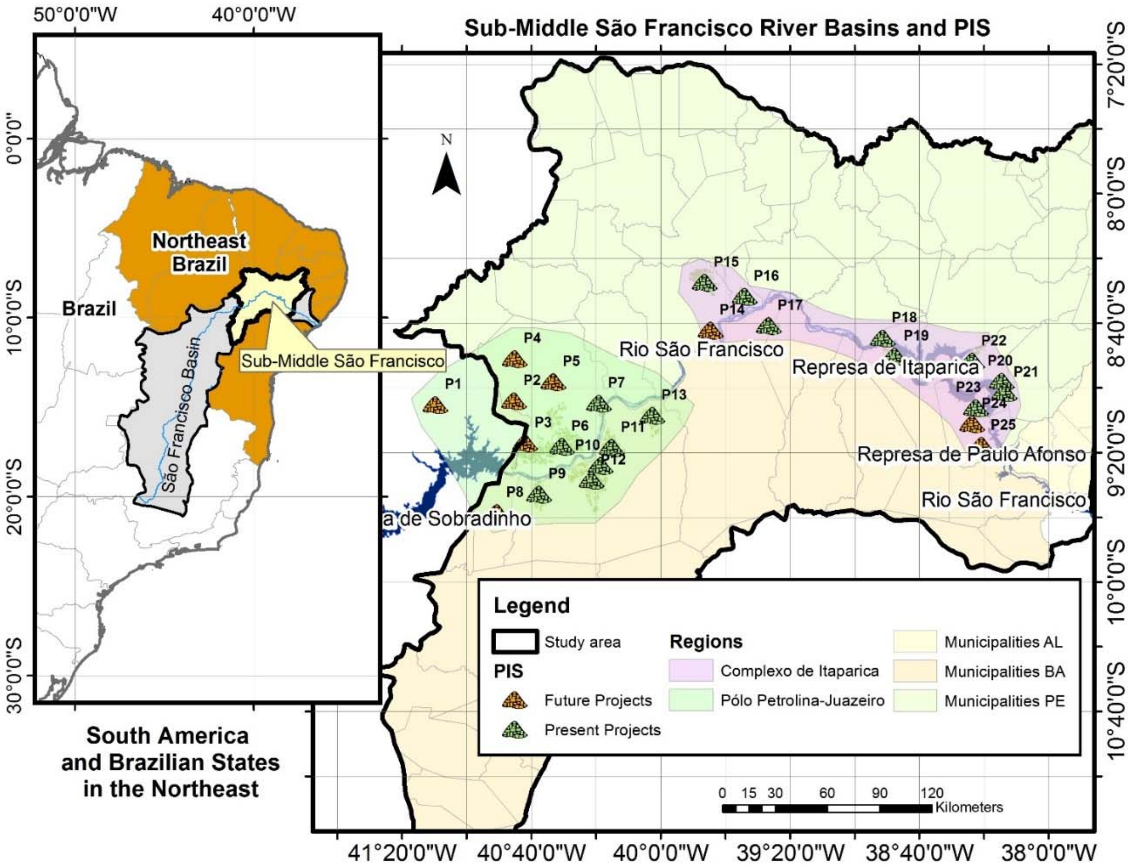


Figure 1 -Study area with the two main regions and its Public Irrigation Schemes (PIS) existing and planned for 2035. [1]

[1] (P1)Cruz das Almas, (P2) Sertão Pernambucano, (P3) Terra Nova, (P4) Pontal Sobradinho, (P5) Pontal, (P6) Nilo Coelho, (P7) Bebedouro, (P8) Serra da Batateira , (P9) Salitre, (P10) Mandacaru , (P11)Maniçoba, (P12)Tourão, (P13)Curaçá, (P14) Brejo de Santa Maria , (P15) Caraibas, (P16) Brigida, (P17) Pedra Branca, (P19) Rodelas, (P20) Apolonio Sales, (P21) Barreiras, (P22) Icó-Mandantes (P23) Gloria, (P24) Dois Irmãos and (P25) Paulo Afonso

TABLES

Table 1 - Current (2006) proportions of crop areas (sugarcane and other crops) in the municipalities containing Public Irrigation Schemes (PIS) considered in our study (FUNARBE)

	Pólo Juazeiro-Petrolina			Complexo de Itaparica						
	Casa Nova	Juazeiro	Petrolina	Curaçá	Rodelas	Glória	Santa Maria da Boa Vista	Orocó	Belém de São Francisco*	Petrolândia
Sugarcane	2%	50%	0%	0%	0%	0%	0%	0%	0%	0%
Banana	1%	0%	8%	5%	0%	4%	13%	20%	0%	10%
Coconut	0%	1%	5%	0%	34%	1%	0%	2%	2%	16%
Goiaba	1%	0%	18%	0%	1%	4%	3%	1%	1%	4%
Mango	44%	26%	36%	4%	8%	1%	2%	2%	7%	2%
Passion fruit	0%	4%	1%	1%	1%	0%	2%	1%	0%	0%
Watermelon	2%	3%	8%	33%	12%	49%	68%	7%	2%	53%
Melon	0%	2%	0%	13%	4%	3%	2%	5%	2%	2%
Tomato	0%	3%	0%	2%	5%	4%	1%	9%	3%	2%
Grapes	11%	5%	16%	0%	0%	0%	1%	0%	0%	0%
Total	**63%**	**93%**	**91%**	**58%**	**66%**	**66%**	**92%**	**47%**	**18%**	**89%**

** Given the low representation of the fruit and sugarcane crops in the municipality area of Belém de São Francisco , the PIS associated to it (Manga de Baixo) was withdrawn from the study.*

Table 2 – Current(2006) proportions of Other Crops areas in the municipalities containing Public Irrigation Schemes (PIS) considered in 2035

Municipality/ Other Crops	Pólo Juazeiro-Petrolina			Complexo de Itaparica					
	Casa Nova	Juazeiro	Petrolina	Curaçá	Rodelas	Glória	Sta Ma. da BV	Orocó	Petrolândia
Banana	2%	1%	8%	9%	0%	6%	14%	44%	11%
Coconut	0%	2%	5%	0%	52%	1%	0%	4%	18%
Goiaba	2%	0%	19%	1%	1%	6%	3%	3%	5%
Mango	73%	60%	40%	7%	12%	1%	3%	4%	3%
Passion Fruit	0%	9%	1%	1%	2%	0%	2%	2%	0%
Watermelon	4%	6%	9%	56%	19%	74%	74%	14%	60%
Melon	1%	6%	0%	22%	5%	5%	2%	10%	2%
Tomato	1%	6%	0%	3%	8%	6%	1%	19%	2%
Grape	18%	11%	17%	1%	0%	0%	1%	0%	1%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 3 - Annual and monthly Sugarcane water requirements updated for 2035 in cubic meters per month per hectare in each municipality.

Municipality / Month	Pólo Juazeiro-Petrolina			Complexo de Itaparica					
	Casa Nova	Juazeiro	Petrolina	Curaçá*	Rodelas*	Glória*	Santa M. da BV *	Orocó	Petrolândia
January	899	1561	1572	1233	1233	1233	1233	1233	899
February	929	1663	1661	1295	1295	1295	1295	1295	929
March	695	1071	1077	885	885	885	885	885	695
April	1101	1806	1808	1454	1454	1454	1454	1454	1101
May	1430	2152	2126	1784	1784	1784	1784	1784	1430
June	1584	2177	2106	1863	1863	1863	1863	1863	1584
July	1722	2313	2239	1999	1999	1999	1999	1999	1722
August	2111	2712	2671	2401	2401	2401	2401	2401	2111
September	2361	3107	3105	2733	2733	2733	2733	2733	2361
October	2291	3188	3192	2740	2740	2740	2740	2740	2291
November	1668	2544	2549	2107	2107	2107	2107	2107	1668
December	1177	1927	1928	1552	1552	1552	1552	1552	1177
Annual Average	1497	2185	2169	1837	1837	1837	1837	1837	1497

**These municipalities had no sugarcane cultivation in 2006 according to the regional data and because of that we used average values of the other municipalities studied.*

Table 4 - Annual and Monthly Weighted Average water requirements for Other crops in cubic meters per month per hectare in each municipality for 2035

Municipality/ Month	Pólo Juazeiro-Petrolina			Complexo de Itaparica					
	Casa Nova	Juazeiro	Petrolina	Curaçá	Rodelas	Glória	Santa M. da BV	Orocó	Petrolândia
January	408	1016	1057	502	721	818	318	675	598
February	434	1259	1392	524	711	790	1135	738	895
March	291	607	747	319	416	589	591	526	418
April	564	1568	1765	812	616	681	862	860	731
May	884	2524	2394	1589	882	604	1466	1154	1509
June	1047	2732	2362	1598	828	552	1721	1156	1976
July	1157	2829	2527	1873	966	497	1541	1199	2062
August	1402	2867	2895	2074	1306	566	1883	1513	2127
September	1517	3511	3784	2566	1569	961	2801	1961	2523
October	1451	3700	3987	2745	1742	1365	3330	2192	2582
November	953	2287	2747	1671	1442	1187	2540	1850	1395
December	620	1848	1985	1168	1027	887	1841	1204	852
Annual Average	894	2229	2303	1453	1019	792	1669	1252	1472

Table 5 - Number of workers per tonnes produced in the baseline year(2006) per crop and municipality

Municipality	**Region**	**Crop Yields (tons/ha)* 2006**		**Number of workers per hectare** (2006)**		**Number of workers per tons produced (2006)**	
		Cane	Other	Cane	Other	Cane	Other
Petrolina	Polo Juazeiro-Petrolina	29	25	0.13	1.34	0.005	0.054
Juazeiro	Polo Juazeiro-Petrolina	90	24	0.13	1.07	0.002	0.045
Casa Nova	Polo Juazeiro Petrolina	39	24	0.13	1.51	0.003	0.064
Petrolandia	Complexo de Itaparica	41	24	0.13	0.75	0.003	0.032
Santa Maria da Boa Vista	Complexo de Itaparica	26	17	0.13	1.34	0.005	0.078
Oroco	Complexo de Itaparica	15	20	0.13	1.73	0.009	0.088
Curaça	Complexo de Itaparica	39	20	0.13	1.62	0.003	0.080
Rodelas	Complexo de Itaparica	41	16	0.13	0.88	0.003	0.056
Gloria	Complexo de Itaparica	41	21	0.13	1.15	0.003	0.054

**An average crop yield in each municipality between 2002 and 2012, obtained using the Municipal Agricultural Production.; **Agricultural Census 2006*

Table 6 - Labor requirements for irrigated area in each municipality for 2035 under A2 scenario with climate change(CC).

PIS	**Region**	**Crop Yields (Tonnes per hectare) 2006**		**Growth rate between 2005 and 2035 given by MagPIE under A2 scenario with cc**		**Crop Yields (Tonnes per hectare) 2035**		**Number of workers per tons produced 2006**		**Number of workers per hectare 2035 (A2 with CC)**	
		Cane	**Others**	**Cane**	**Others**	**Cane**	**Others**	**Cane**	**Others**	**Cane**	**Others**
Nilo coelho	Polo Juazeiro-Petrolina	29	25	1.07	0.958	31	24	0.0047	0.0544	0.15	1.29
Bebedouro	Polo Juazeiro-Petrolina	29	25	1.03	0.959	30	24	0.0047	0.0544	0.14	1.29
Salitre	Polo Juazeiro-Petrolina	90	24	1.07	0.958	97	23	0.0015	0.0452	0.15	1.04
Mandacaru	Polo Juazeiro-Petrolina	90	24	1.03	0.959	92	23	0.0015	0.0452	0.14	1.04
Tourão	Polo Juazeiro-Petrolina	90	24	1.03	0.959	92	23	0.0015	0.0452	0.14	1.04
Maniçoba	Polo Juazeiro-Petrolina	90	24	1.03	0.959	92	23	0.0015	0.0452	0.14	1.04
Curaçá	Polo Juazeiro-Petrolina	90	24	1.03	0.959	92	23	0.0015	0.0452	0.14	1.04
Terra Nova	Polo Juazeiro-Petrolina	29	25	1.07	0.958	31	24	0.0047	0.0544	0.15	1.29
Pontal Sobradinho	Polo Juazeiro-Petrolina	29	25	1.07	0.958	31	24	0.0047	0.0544	0.15	1.29
Pontal	Polo Juazeiro-Petrolina	29	25	1.03	0.959	30	24	0.0047	0.0544	0.14	1.29
Serra da Batateira	Polo Juazeiro-Petrolina	90	24	1.07	0.958	97	23	0.0015	0.0452	0.15	1.04
Cruz das Almas	Polo Juazeiro-Petrolina	39	24	1.07	0.958	42	23	0.0035	0.0640	0.15	1.45

Sertão Pernumbucano	Polo Juazeiro-Petrolina	39	24	1.07	0.958	42	23	0.0035	0.0640	0.15	1.45
I Mandantes	Complexo de Itaparica	41	24	1.03	0.959	42	23	0.0033	0.0321	0.14	0.72
A Sales	Complexo de Itaparica	41	24	1.03	0.959	42	23	0.0033	0.0321	0.14	0.72
Barreiras	Complexo de Itaparica	41	24	1.02	0.956	42	23	0.0033	0.0321	0.14	0.72
Caraibas	Complexo de Itaparica	26	17	1.03	0.959	27	17	0.0051	0.0780	0.14	1.29
Brigida	Complexo de Itaparica	15	20	1.03	0.959	15	19	0.0090	0.0880	0.14	1.66
P Branca	Complexo de Itaparica	39	20	1.03	0.959	41	19	0.0034	0.0801	0.14	1.56
Brejo de Santa Maria	Complexo de Itaparica	26	17	1.03	0.959	27	17	0.0051	0.0780	0.14	1.29
Rodelas	Complexo de Itaparica	41	16	1.03	0.959	42	15	0.0033	0.0557	0.14	0.85
Gloria	Complexo de Itaparica	41	21	1.02	0.956	42	20	0.0033	0.0545	0.14	1.10
Dois Irmãos	Complexo de Itaparica	41	21	1.02	0.956	42	20	0.0033	0.0545	0.14	1.10
Paulo Afonso	Complexo de Itaparica	41	21	1.02	0.956	42	20	0.0033	0.0545	0.14	1.10

-

Table 7 - The value for supplies per production units inThousand Reais (BRL - Brazilian currency) per tonnes produced in 2006 obtained from value for supplies per irrigated area and crop yields .

Municipality	Region	Supplies per hectare in Thousand BRL* (2006)		Thousand BRL per TON 2006**	
		Cane	Others	Cane	Others
Petrolina	Polo Juazeiro-Petrolina	0.86	6.14	0.0302	0.24
Juazeiro	Polo Juazeiro-Petrolina	0.86	3.94	0.0097	0.16
Casa Nova	Polo Juazeiro-Petrolina	0.86	4.71	0.0225	0.19
Petrolandia	Complexo de Itaparica	0.86	1.16	0.0211	0.04
Santa Maria da Boa Vista	Complexo de Itaparica	0.86	1.37	0.0328	0.07
Oroco	Complexo de Itaparica	0.86	0.99	0.0402	0.04
Curaça	Complexo de Itaparica	0.86	2.10	0.0211	0.09
Santa Maria da Boa Vista	Complexo de Itaparica	0.86	1.37	0.0328	0.07
Rodelas	Complexo de Itaparica	0.86	1.48	0.0211	0.09
Gloria	Complexo de Itaparica	0.86	0.98	0.0211	0.04

Agricultural Census 2006; Obtained from the ratio between the first columns and the crop yields for 2006.*

Table 8 - Supply requirements for irrigated area in each municipality and Public Irrigation Scheme (PIS) for 2035 under A2 scenario with climate change(CC).

PIS	Region	Crop Yields (TONNES/ HECTARE) 2006		Growth rate between 2005 and 2035 given by MagPIE under A2 scenario with cc		Crop Yields (TONNES/ HECTARE) 2035		Supplies requirement per ton produced (Thousands BRL/ TONNES) 2006		Supplies requirement per hectare (Thousands BRL/ HECTARE) 2035 A2 with CC	
		Cana	Outras	Cana	Outras	Cana	Outras	Cana	Outras	Cana	Outras
Nilo coelho	Polo Juazeiro-Petrolina	29	25	1.07	0.958	31	24	0.030	0.248	0.93	5.89
Bebedouro	Polo Juazeiro-Petrolina	29	25	1.03	0.959	30	24	0.030	0.248	0.89	5.89
Salitre	Polo Juazeiro-Petrolina	90	24	1.07	0.958	97	23	0.009	0.165	0.93	3.78
Mandacaru	Polo Juazeiro-Petrolina	90	24	1.03	0.959	92	23	0.009	0.165	0.89	3.78
Tourão	Polo Juazeiro-Petrolina	90	24	1.03	0.959	92	23	0.009	0.165	0.89	3.78
Maniçoba	Polo Juazeiro-Petrolina	90	24	1.03	0.959	92	23	0.009	0.165	0.89	3.78
Curaçá	Polo Juazeiro-Petrolina	90	24	1.03	0.959	92	23	0.009	0.165	0.89	3.78
Terra Nova	Polo Juazeiro-Petrolina	29	25	1.07	0.958	31	24	0.030	0.248	0.93	5.89
Pontal Sobradinho	Polo Juazeiro-Petrolina	29	25	1.07	0.958	31	24	0.030	0.248	0.93	5.89
Pontal	Polo Juazeiro-Petrolina	29	25	1.03	0.959	30	24	0.030	0.248	0.89	5.89
Serra da Batateira	Polo Juazeiro-Petrolina	90	24	1.07	0.958	97	23	0.009	0.165	0.93	3.78
Cruz das Almas	Polo Juazeiro-Petrolina	39	24	1.07	0.958	42	23	0.022	0.198	0.93	4.52
Sertão Pernumbucano	Polo Juazeiro-Petrolina	39	24	1.07	0.958	42	23	0.022	0.198	0.93	4.52
I Mandanes	Complexo de Itaparica	41	24	1.03	0.959	42	23	0.021	0.049	0.89	1.12
A Sales	Complexo de Itaparica	41	24	1.03	0.959	42	23	0.021	0.049	0.89	1.12
Barreiras	Complexo de Itaparica	41	24	1.02	0.956	42	23	0.021	0.049	0.89	1.11
Caraibas	Complexo de Itaparica	26	17	1.03	0.959	27	17	0.032	0.079	0.89	1.31
Brigida	Complexo de Itaparica	15	20	1.03	0.959	15	19	0.057	0.050	0.89	0.95
P Branca	Complexo de Itaparica	39	20	1.03	0.959	41	19	0.022	0.103	0.89	2.02
Brejo de Santa Maria	Complexo de Itaparica	26	17	1.03	0.959	27	17	0.032	0.079	0.89	1.31
Rodelas	Complexo de Itaparica	41	16	1.03	0.959	42	15	0.021	0.093	0.89	1.42
Gloria	Complexo de Itaparica	41	21	1.02	0.956	42	20	0.021	0.046	0.89	0.94

Dois Irmãos	Complexo de Itaparica	41	21	1.02	0.956	42	20	0.021	0.046	0.89	0.94
Paulo Afonso	Complexo de Itaparica	41	21	1.02	0.956	42	20	0.021	0.046	0.89	0.94

Table 9 - Land variable costs in 2006 and updated for 2035 in the current Public Irrigation Schemes (PIS) under A2 scenario with Climate Change (CC) using the growth rate of production costs given by MagPIE between 2005 and 2035.

PIS	Municipality	Regions	Land variable costs in 2006 in Thousands BRL per hectare	K1 charged in 2006**(Thousand BRL per hectare)	A2_with CC (2035)	
					Land variable costs (Thousands BRL per hectare)	K1 (Thousands BRL per hectare)
Nilo coelho	Petrolina	Polo Juazeiro-Petrolina	0.509	0.084	0.784	0.130
Bebedouro	Petrolina	Polo Juazeiro-Petrolina	0.509	0.075	0.784	0.115
Salitre	Juazeiro	Polo Juazeiro-Petrolina	0.532	0.075	0.818	0.115
Mandacaru**	Juazeiro	Polo Juazeiro-Petrolina	0.532	0.045	0.818	0.069
Tourão	Juazeiro	Polo Juazeiro-Petrolina	0.532	0.075	0.818	0.115
Maniçoba	Juazeiro	Polo Juazeiro-Petrolina	0.532	0.048	0.818	0.074
Curaçá**	Juazeiro	Polo Juazeiro-Petrolina	0.532	0.075	0.818	0.115
Terra Nova**	Petrolina	Polo Juazeiro-Petrolina	0.509	0.075	0.784	0.115
Pontal Sobradinho**	Petrolina	Polo Juazeiro-Petrolina	0.509	0.075	0.784	0.115
Pontal**	Petrolina	Polo Juazeiro-Petrolina	0.509	0.075	0.784	0.115
Serra da Batateira**	Juazeiro	Polo Juazeiro-Petrolina	0.532	0.075	0.818	0.115
Cruz das Almas**	Casa Nova *	Polo Juazeiro-Petrolina	0.520	0.075	0.801	0.115
Sertão Pernamb.**	Casa Nova *	Polo Juazeiro-Petrolina	0.520	0.075	0.801	0.115
I Mandanes	Petrolandia	Complexo de Itaparica	0.098	0.075	0.151	0.115
A Sales	Petrolandia	Complexo de Itaparica	0.098	0.054	0.151	0.083
Barreiras	Petrolandia	Complexo de Itaparica	0.098	0.054	0.151	0.083
Caraibas	Santa Maria da Boa Vista	Complexo de Itaparica	0.172	0.075	0.264	0.115
Brigida	Oroco	Complexo de Itaparica	0.130	0.054	0.200	0.083
P Branca	Curaça	Complexo de Itaparica	0.140	0.075	0.216	0.115
Brejo de S.M.**	Santa Maria da Boa Vista	Complexo de Itaparica	0.172	0.075	0.264	0.115

Rodelas**	Rodelas*	Complexo de Itaparica	0.098	0.045	0.151	0.069
Gloria**	Gloria*	Complexo de Itaparica	0.098	0.045	0.151	0.069
Dois Irmãos**	Gloria*	Complexo de Itaparica	0.098	0.075	0.151	0.115
Paulo Afonso**	Gloria*	Complexo de Itaparica	0.098	0.075	0.151	0.115

** For these municipalities Land variable costs in 2006 are average values or proxies ; **New PIS not existing in 2006 has its K1 in the baseline related to size.*

Table 10 - Variable Labor Costs in Thousands of Brazilian currency/worker in each municipality (Census Data 2006) projected for the future using MagPIE growth rate of production costs and crop yields changes under A2 scenario with Climate Change (CC).

Labor variable costs in Thousand Brazilian Currency (Reais or BRL) per worker in the baseline and under A2 scenarios with Climate Change(CC)					
PIS	Municipality	Region	Baseline (2006)	A2_with_CC (2035)	
				CANE	OTHER
Nilo coelho	Petrolina	Polo Juazeiro-Petrolina	1.89	2.86	2.85
Bebedouro	Petrolina	Polo Juazeiro-Petrolina	1.89	2.99	2.84
Salitre	Juazeiro	Polo Juazeiro-Petrolina	2.41	3.65	3.64
Mandacaru	Juazeiro	Polo Juazeiro-Petrolina	2.41	3.82	3.63
Tourão	Juazeiro	Polo Juazeiro-Petrolina	2.41	3.82	3.63
Maniçoba	Juazeiro	Polo Juazeiro-Petrolina	2.41	3.82	3.63
Curaçá	Juazeiro	Polo Juazeiro-Petrolina	2.41	3.82	3.63
Terra Nova	Petrolina	Polo Juazeiro-Petrolina	1.89	2.86	2.85
Pontal Sobradinho	Petrolina	Polo Juazeiro-Petrolina	1.89	2.86	2.85
Pontal	Petrolina	Polo Juazeiro-Petrolina	1.89	2.99	2.84
Serra da Batateira	Juazeiro	Polo Juazeiro-Petrolina	2.41	3.65	3.64
Cruz das Almas	Casa Nova	Polo Juazeiro-Petrolina	0.46	0.69	0.69
Sertão Pernambucano	Casa Nova	Polo Juazeiro-Petrolina	0.46	0.69	0.69
I Mandanes	Petrolandia	Complexo de Itaparica	0.28	0.45	0.43
A Sales	Petrolandia	Complexo de Itaparica	0.28	0.45	0.43
Barreiras	Petrolandia	Complexo de Itaparica	0.28	0.45	0.43
Caraibas	Santa Maria da BV	Complexo de Itaparica	0.19	0.30	0.29
Brigida	Oroco	Complexo de Itaparica	0.06	0.09	0.09
P Branca	Curaça	Complexo de Itaparica	0.28	0.45	0.43
Brejo de Santa Maria	Santa Maria da BV	Complexo de Itaparica	0.19	0.30	0.29
Rodelas	Rodelas	Complexo de Itaparica	0.16	0.25	0.24
Gloria	Gloria	Complexo de Itaparica	0.09	0.15	0.14
Dois Irmãos	Gloria	Complexo de Itaparica	0.09	0.15	0.14
Paulo Afonso	Gloria	Complexo de Itaparica	0.09	0.15	0.14

Table 11 - Variable costs for water in Thousand Reais(BRL - Brazilian Currency) per Thousands of cubic meters in the baseline and under A2 scenario with climate change (CC)

Variable costs for water in Thousand Reais(BRL) per Thousands of cubic meters in the baseline and under A2 scenario with climate change					
PIS	Municipality	Region	Baseline (2006)	A2_with CC (2035)	
				CANE	OTHER
Nilo coelho	Petrolina	Polo Juazeiro-Petrolina	0.123	0.199	0.175
bebedouro	Petrolina	Polo Juazeiro-Petrolina	0.077	0.124	0.109
salitre	Juazeiro	Polo Juazeiro-Petrolina	0.075	0.120	0.105
Mandacaru	Juazeiro	Polo Juazeiro-Petrolina	0.093	0.150	0.131
Tourão	Juazeiro	Polo Juazeiro-Petrolina	0.038	0.061	0.053
Maniçoba	Juazeiro	Polo Juazeiro-Petrolina	0.080	0.128	0.112
Curaçá	Juazeiro	Polo Juazeiro-Petrolina	0.055	0.088	0.077
Terra Nova	Petrolina	Polo Juazeiro-Petrolina	0.093	0.151	0.133
Pontal Sobradinho	Petrolina	Polo Juazeiro-Petrolina	0.093	0.151	0.133
Pontal	Petrolina	Polo Juazeiro-Petrolina	0.093	0.151	0.133
Serra da Batateira	Juazeiro	Polo Juazeiro-Petrolina	0.093	0.150	0.131
Cruz das Almas	Casa Nova	Polo Juazeiro-Petrolina	0.093	0.149	0.130
Sertão Pernambucano	Casa Nova	Polo Juazeiro-Petrolina	0.093	0.149	0.130
I Mandanes	Petrolandia	Complexo de Itaparica	0.075	0.120	0.096
A Sales	Petrolandia	Complexo de Itaparica	0.075	0.120	0.096
Barreiras	Petrolandia	Complexo de Itaparica	0.075	0.120	0.096
Caraibas	Santa Maria da BV	Complexo de Itaparica	0.075	0.120	0.106
Brigida	Oroco	Complexo de Itaparica	0.075	0.120	0.106
P Branca	Curaça	Complexo de Itaparica	0.075	0.120	0.103
Brejo de Santa Maria	Santa Maria da BV	Complexo de Itaparica	0.075	0.120	0.106
Rodelas	Rodelas	Complexo de Itaparica	0.075	0.120	0.104
Gloria	Gloria	Complexo de Itaparica	0.075	0.120	0.103
Dois Irmãos	Gloria	Complexo de Itaparica	0.075	0.120	0.103
Paulo Afonso	Gloria	Complexo de Itaparica	0.075	0.120	0.103

Table 12 - Supplies variable costs in the baseline and under A2 scenario with climate change(adimensional)

Supplies variable costs in the baseline and under A2 scenario with climate change(adimensional)					
PIS	Municipality	Region	Baseline (2006)	A2_cc (2035)	
				CANE	OTHER
Nilo coelho	Petrolina	Polo Juazeiro-Petrolina	1.06	1.60	1.597
Bebedouro	Petrolina	Polo Juazeiro-Petrolina	1.06	1.67	1.595
Salitre	Juazeiro	Polo Juazeiro-Petrolina	1.06	1.60	1.597
Mandacaru	Juazeiro	Polo Juazeiro-Petrolina	1.06	1.67	1.595
Tourão	Juazeiro	Polo Juazeiro-Petrolina	1.06	1.67	1.595
Maniçoba	Juazeiro	Polo Juazeiro-Petrolina	1.06	1.67	1.595
Curaçá	Juazeiro	Polo Juazeiro-Petrolina	1.06	1.67	1.595
Terra Nova	Petrolina	Polo Juazeiro-Petrolina	1.06	1.60	1.597
Pontal Sobradinho	Petrolina	Polo Juazeiro-Petrolina	1.06	1.60	1.597
Pontal	Petrolina	Polo Juazeiro-Petrolina	1.06	1.67	1.595
Serra da Batateira	Juazeiro	Polo Juazeiro-Petrolina	1.06	1.60	1.597
Cruz das Almas	Casa Nova	Polo Juazeiro-Petrolina	1.06	1.60	1.597
Sertão Pernambucano	Casa Nova	Polo Juazeiro-Petrolina	1.06	1.60	1.597
I Mandanes	Petrolandia	Complexo de Itaparica	1.06	1.67	1.595
A Sales	Petrolandia	Complexo de Itaparica	1.06	1.67	1.595
Barreiras	Petrolandia	Complexo de Itaparica	1.06	1.68	1.600
Caraibas	Santa Maria da BV	Complexo de Itaparica	1.06	1.67	1.595
Brigida	Oroco	Complexo de Itaparica	1.06	1.67	1.595
P Branca	Curaça	Complexo de Itaparica	1.06	1.67	1.595
Brejo de Santa Maria	Santa Maria da BV	Complexo de Itaparica	1.06	1.67	1.595
Rodelas	Rodelas	Complexo de Itaparica	1.06	1.67	1.595
Gloria	Gloria	Complexo de Itaparica	1.06	1.68	1.600
Dois Irmãos	Gloria	Complexo de Itaparica	1.06	1.68	1.600
Paulo Afonso	Gloria	Complexo de Itaparica	1.06	1.68	1.600

Table 13 - Average Prices in Thousands Reais (BRL -Brazilian Currency) per Tonnes produced in the baseline year and under A2 scenario with climate change(CC) using growth rate of production costs by crops.

PIS	Municipality	Regions	Average Price (2006)		Average Price A2_with_CC (2035)	
			Cane	Others	Cane	Others
Nilo coelho	Petrolina	Polo Juazeiro-Petrolina	0.097	0.842	0.158	1.217
Bebedouro	Petrolina	Polo Juazeiro-Petrolina	0.097	0.842	0.158	1.217
Salitre	Juazeiro	Polo Juazeiro-Petrolina	0.101	0.689	0.164	0.996
Mandacaru	Juazeiro	Polo Juazeiro-Petrolina	0.101	0.689	0.164	0.996
Tourão	Juazeiro	Polo Juazeiro-Petrolina	0.101	0.689	0.164	0.996
Maniçoba	Juazeiro	Polo Juazeiro-Petrolina	0.101	0.689	0.164	0.996
Curaçá	Juazeiro	Polo Juazeiro-Petrolina	0.101	0.689	0.164	0.996
Terra Nova	Petrolina	Polo Juazeiro-Petrolina	0.097	0.842	0.158	1.217
Pontal Sobradinho	Petrolina	Polo Juazeiro-Petrolina	0.097	0.842	0.158	1.217
Pontal	Petrolina	Polo Juazeiro-Petrolina	0.097	0.842	0.158	1.217
Serra da Batateira	Juazeiro	Polo Juazeiro-Petrolina	0.101	0.689	0.164	0.996
Cruz das Almas	Casa Nova	Polo Juazeiro-Petrolina	0.079	0.756	0.129	1.093
Sertão Pernumbocano	Casa Nova	Polo Juazeiro-Petrolina	0.079	0.756	0.129	1.093
I Mandanes	Petrolandia	Complexo de Itaparica	0.090	0.371	0.147	0.536
A Sales	Petrolandia	Complexo de Itaparica	0.090	0.371	0.147	0.536
Barreiras	Petrolandia	Complexo de Itaparica	0.090	0.371	0.147	0.536
Caraibas	Santa Maria da BV	Complexo de Itaparica	0.088	0.394	0.145	0.570
Brigida	Oroco	Complexo de Itaparica	0.085	0.597	0.138	0.863
P Branca	Curaça	Complexo de Itaparica	0.090	0.405	0.147	0.584
Brejo de Santa Maria	Santa Maria da BV	Complexo de Itaparica	0.090	0.498	0.147	0.719
Rodelas	Rodelas	Complexo de Itaparica	0.090	0.301	0.147	0.435
Gloria	Gloria	Complexo de Itaparica	0.090	0.321	0.147	0.435
Dois Irmãos	Gloria	Complexo de Itaparica	0.090	0.321	0.147	0.463
Paulo Afonso	Gloria	Complexo de Itaparica	0.090	0.321	0.147	0.463

Table 14 - Annual Average Coefficients of water requirement per crop and per municipality in the baseline year (2006) and projected values for 2035 under A2 scenario with climate change (CC) (m3/month.hectare)

Municipality/ Crop and scenarios	Pólo Juazeiro-Petrolina			Complexo de Itaparica					
	Casa Nova	Juazeiro	Petrolina	Curaçá	Rodelas	Glória	Santa Maria da Boa Vista	Orocó	Petrolândia
Sugarcane (2006)	1464	2152	2153	1808	1808	1808	1808	1808	1808
Sugarcane 2035 (A2_with_CC)	1497	2185	2169	1837	1837	1837	1837	1837	1837
Other Crops (2006)	866	2172	2275	1398	986	762	1640	1237	1318
Other crops 2035(A2_with _CC)	894	2229	2303	1453	1019	792	1669	1252	1472

Table 15 - Economic values of water obtained for each PIS with 100% of water availability in the baseline year and under A2 scenario with climate change(CC)

PIS	Municipality	Region	Water Unit Costs (2006) BRL/1000m3	Economic value of water (2006) BRL/1000 m3	Water Unit Costs (2035) A2 w CC BRL/1000m3	Economic value of water (2035) A2 with CC BRL/1000m 3
Nilo coelho	Petrolina	Polo Juazeiro-Petrolina	120	187	180	227
Bebedouro	Petrolina	Polo Juazeiro-Petrolina	80	430	110	453
Salitre	Juazeiro	Polo Juazeiro-Petrolina	70	1,323	113	2,406
Mandacaru	Juazeiro	Polo Juazeiro-Petrolina	-	-	140	1,776
Tourão	Juazeiro	Polo Juazeiro-Petrolina	90	891	140	1,486
Maniçoba	Juazeiro	Polo Juazeiro-Petrolina	80	1,268	120	2,487
Curaçá	Juazeiro	Polo Juazeiro-Petrolina	60	1,300	85	2,524
Terra Nova	Petrolina	Polo Juazeiro-Petrolina	-	0	130	248
Pontal Sobradinho	Petrolina	Polo Juazeiro-Petrolina	-	0	130	191
Pontal	Petrolina	Polo Juazeiro-Petrolina	-	0	130	991
Serra da Batateira	Juazeiro	Polo Juazeiro-Petrolina	-	0	131	709
Cruz das Almas	Casa Nova	Polo Juazeiro-Petrolina	-	0	130	953
Sertão Pernam.	Casa Nova	Polo Juazeiro-Petrolina	-	0	130	821
I Mandanes	Petrolandia	Complexo de Itaparica	70	162	100	752
A Sales	Petrolandia	Complexo de Itaparica	70	186	100	798
Barreiras	Petrolandia	Complexo de Itaparica	70	191	100	784
Caraibas	Santa Maria da Boa Vista	Complexo de Itaparica	70	229	110	337
Brigida	Oroco	Complexo de Itaparica	70	269	110	334
P Branca	Curaça	Complexo de Itaparica	70	137	100	632
Brejo de Santa Maria	Santa Maria da Boa Vista	Complexo de Itaparica	-	0	110	226
Rodelas	Rodelas	Complexo de Itaparica	-	0	100	556
Gloria	Gloria	Complexo de Itaparica	-	0	100	1,076
Dois Irmãos	Gloria	Complexo de Itaparica	-	0	100	284
Paulo Afonso	Gloria	Complexo de Itaparica	-	0	100	430

The impact of global changes on economic values of water for Public Irrigation Schemes at the São Francisco River Basin in Brazil. *Regional Environmental Change*. Alcoforado de Moraes*, MMG., Biewald, A., Carneiro, ACG.,da Silva, G.N.S., Popp, A., Lotze-Campen, H.*UFPE, marcia.alcoforado@ufpe.br.

Online Resource 2

Table 1 - Regions studied with current and planned areas for 2035 with Public Irrigation Schemes (PIS), municipalities and states.

Regions		Total Area with PIS (1000 hectares)	PIS numbers[1]	Municipalities	States of Brazil
Pólo Juazeiro-Petrolina	Baseline Year (2006) (CODEVASF 2006)	10.51	P6, P7	Petrolina	Pernambuco (PE)
		25.08	P9, P11,P12,P13	Juazeiro	Bahia (BA)
	Planned by Brazilian Government (2035) (Agência Nacional de Águas - ANA, 2012)	65.07	P1, P2	Casa Nova	Bahia
		88.28	P3 to P7	Petrolina	Pernambuco
		69.49	P8 to P13	Juazeiro	Bahia
Complexo de Itaparica	Baseline Year (2006) (CODEVASF 2006)	2.90	P15	Santa Maria da Boa Vista	Pernambuco (PE)
		0.41	P16	Oroco	Pernambuco (PE)
		1.57	P17	Curaçá	Bahia (BA)
		2.11	P20 to P22	Petrolândia	Pernambuco (PE)
	Planned by Brazilian Government (2035) (Agência Nacional de Águas - ANA, 2012)	9.02	P14, P15	Santa Maria da Boa Vista	Pernambuco (PE)
		1.43	P16	Orocó	Pernambuco (PE)
		2.44	P17	Curaçá	Bahia (BA)
		1.66	P19	Rodelas	Bahia(BA)
		4.24	P20 to P22	Petrolândia	Pernambuco (PE)
		62.38	P23 to P25	Gloria	Bahia(BA)

[1] (P1)Cruz das Almas, (P2) Sertão Pernambucano, (P3) Terra Nova, (P4) Pontal Sobradinho, (P5) Pontal, (P6) Nilo Coelho, (P7) Bebedouro, (P8) Serra da Batateira , (P9) Salitre, (P10) Mandacaru , (P11)Maniçoba, (P12)Tourão, (P13)Curaçá, (P14) Brejo de Santa Maria , (P15) Caraibas, (P16) Brigida, (P17) Pedra Branca, (P19) Rodelas, (P20) Apolonio Sales, (P21) Barreiras, (P22) Icó-Mandantes (P23) Gloria, (P24) Dois Irmãos and (P25) Paulo Afonso.

Table 2 - Comparison of two land use data sets (MODIS and MIRCA) with simulation results of MAgPIE, for cropland, and natural vegetation and pasture for the year 1995 (in mio. ha) in the SFRB.

	MAgPIE	MODIS	MIRCA
Cropland	4.3	1.9	6.2
Natural Vegetation + Pasture	57.1	60.2	-

Table 3 - Characteristics of the A2 scenario with climate change, for the São Francisco River Basin (SFRB) and the year 2035. Data are taken partially from the GLUES data base.

Parameters	**A2 with climate change**	**Data source**
Population (in mill. people)	299 in Brazil (compared to 231 in 2005) 900 in Latin America (compared to 573 in 2005) fast increasing	GLUES (http://geoportal-glues.ufz.de/inform/about.html)
GDP per capita in US$/a	9680 Latin America (poor)	GLUES
Climate	between 2°C and 5.4°C global average warming until the end of the century	GLUES
Kcal per capita and day	3129	Own calculations using the methodology described in Bodirsky et al. (2015)
Livestock share in the overall diet	0.22	Own calculations using the methodology described in Bodirsky et al. (2015)
Water availability in km^3	134	GLUES (LPJmL, average of 3 GCMS) (http://geoportal-glues.ufz.de/inform/about.html)

FIGURES

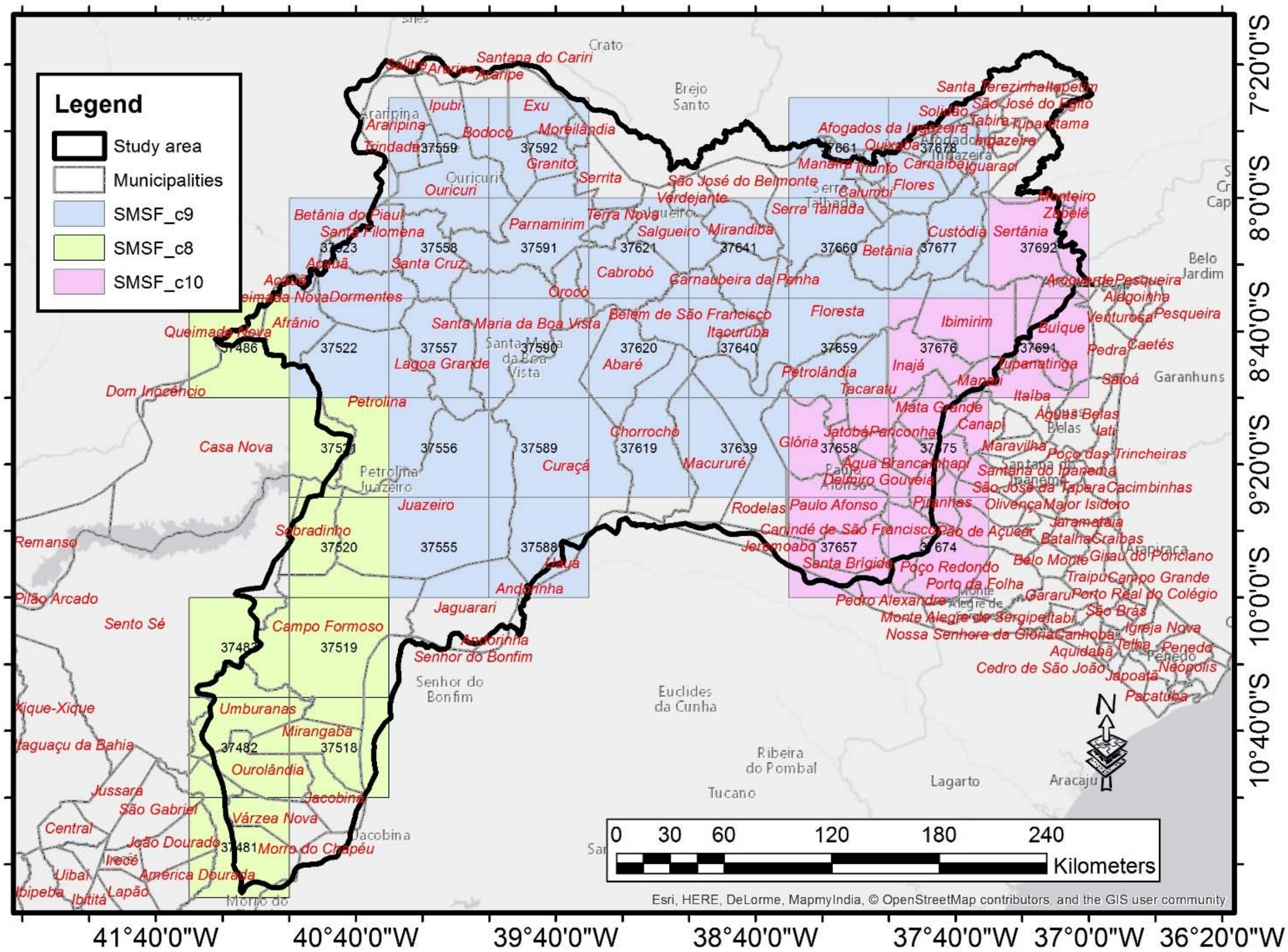


Figure 1: Simulation units from MAgPIE (clusters) matched to the municipalities in the Sub-Middle of the São Francisco River Basin (SM-SFRB).

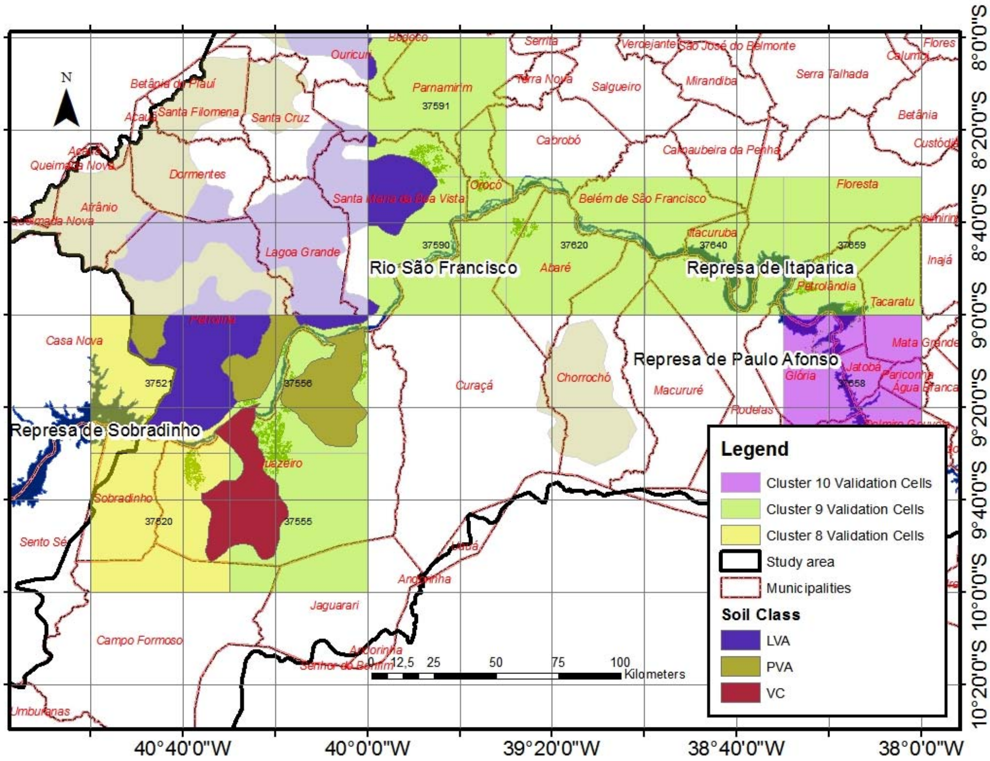


Figure 2 - The soil types adequate for sugarcane at Sub-Middle of the São Francisco River Basin (SM-SFRB) and clusters/ cells used for downscaling of cultivated area estimated by MAgPIE in 2005.

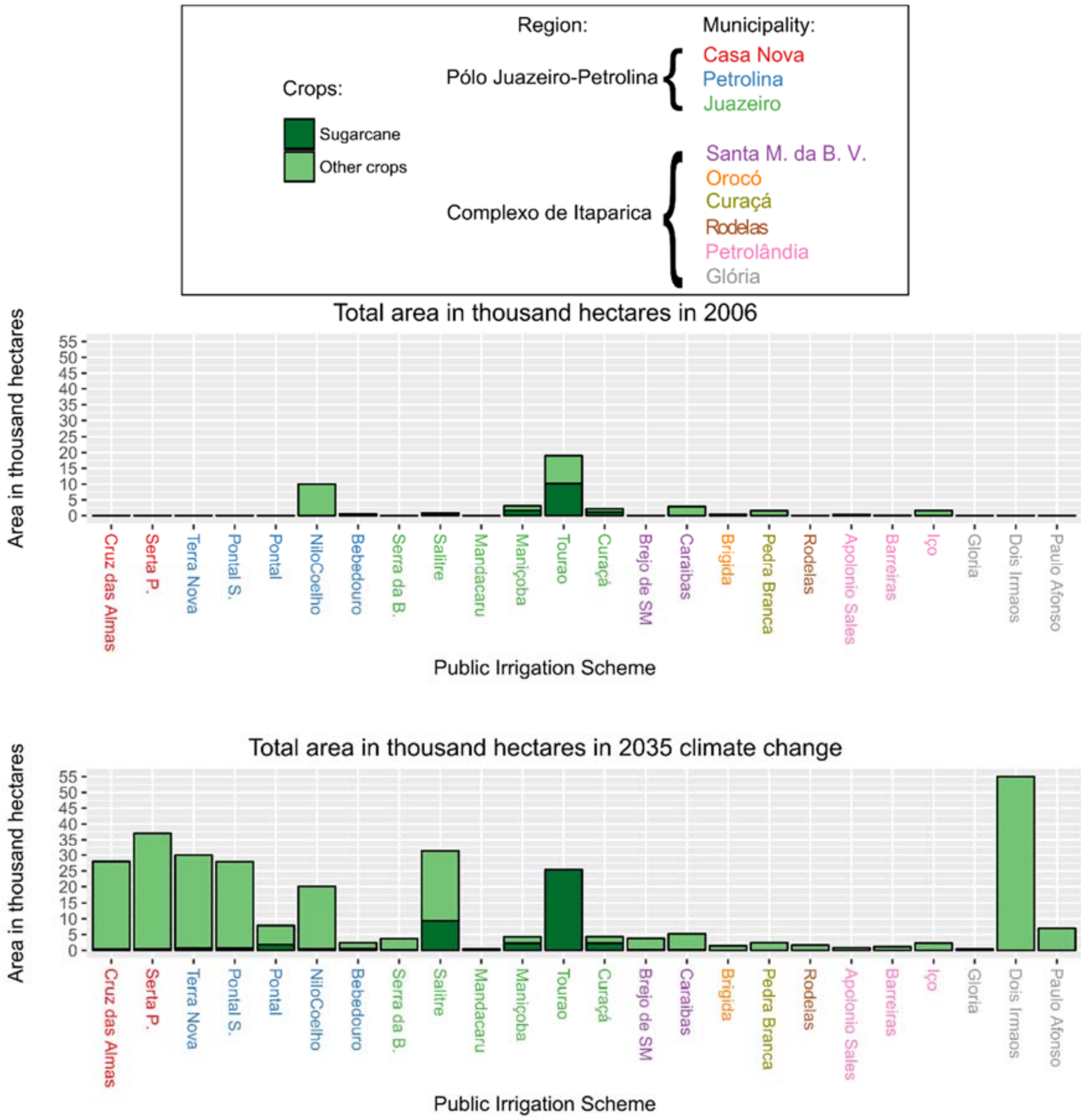


Figure 3 - Agricultural land use for sugar cane and other crops in the different Public Irrigation Schemes(PIS) in the baseline year and under the A2 scenario with Climate Change(CC)