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Sugarcane water footprint in the suitable areas for crop in Brazil

Policy brief #1

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1. Summary

The expansion of sugarcane in Brazil, largely for biofuel production, prompted the Brazilian government to establish Agroecological Zoned areas for sugarcane agriculture. The objective of this study was to assess, in the Agroecological Zoned areas for sugarcane across Brazil, the water footprint (WF) and water stress yield reduction for sugarcane agriculture under rainfed conditions and the water irrigation requirement under full irrigation.

The WF generally includes the blue WF (surface and groundwater resources allocated by humans, usually for irrigation), green WF (soil moisture, mostly from rainfall which is consumed through crop evapotranspiration, ET), and gray WF (freshwater volume needed to assimilate associated pollutant loads).[1] In this study we do not assess the gray WF.

The green and blue WFs were estimated for agricultural phase of plant cane and for the 4th ratoon. The yield reductions under rainfed conditions are higher than 50% in over 60% of the total suitable areas for sugarcane, indicating that irrigation would be important to increase the productivity. The center-south of Brazil which produces most of the sugarcane has net irrigation requirements ranging from 200 to 700 mm/cycle. The highest water irrigation requirements were observed in the Brazilian Northeastern, reaching net irrigation higher than 800 mm/cycle. The average sugarcane WF (blue and green water) in Brazil is 103 m^3/Mg for plant cane and 160 m^3/Mg for the 4th ratoon.

Locations with larger blue WF indicate the need for irrigation because rainfall is low. Thus, areas with high blue WF indicate that planting cane in those areas could put additional stress on water resources if irrigation was used. For example, in northeastern Brazil the green WF fraction decreases and water stress-related yield reduction increases indicating the importance of irrigation (and significant blue WF) in sugarcane cultivation in that region. The large fraction of green WF (>70 %) in the center-south of Brazil which covers 72% of the total suitable areas for sugarcane confirms that rainfall is much more sufficient for sugarcane production.

Considering broad information on water quantity and quality, there does not appear to be significant pressure on water resources close to potential areas for sugarcane in the center of Brazil, which may favor its expansion, but studies in specific locations (e.g., water basins) are important for a

more detailed analysis of sustainability of sugarcane productions in a local level.

2. Methodology

The suitable areas for sugarcane expansion in Brazil (65 million ha) determined by the ZAE-Cana[2] include 2824 municipalities across 21 States and five regions (Southeast, South, Center-West, North, and Northeast).

To estimate the sugarcane yield reduction (YR, %) due to water stress and the net irrigation requirement to reach 0% YR, the following parameters are required: climate during cultivation, planting date, and crop parameters. The sugarcane planting-harvest cycle is assumed to equal 12 months such that the planting and harvesting dates coincide. The percentage yield reduction under rainfed conditions and the net irrigation requirement under full irrigation to meet the crop needs were estimated in each municipality for the period 1980-2013. Daily rainfall and reference ET (ET_0) data are based on a high-resolution gridded (0.25°×0.25°) daily data set developed by Xavier et al.[3] based on the most comprehensive ground-based station data available for Brazil. The ET data are based on the Penman-Monteith equation from this study also. The sequence of methods used is described in the following section.

The blue and green water footprints (WFs) were estimated for plant cane and for the 4th ratoon in the agricultural phase according to the methods outlined in the "Water Footprint Assessment Manual".[1] The green WF (WFgreen, m^3/Mg) is defined as the amount of rainwater (stored in the soil as soil moisture) used by plants, given as the minimum between effective rainfall (R_{eff}, mm) and the actual (adjusted) crop ET as a result of environmental or water stresses, divided by crop yield (Mg/ha) (Equation 1). The effective rainfall is part of the total rainfall that is stored in the root zone and can be used by plants, after subtracting losses from deep percolation and surface runoff.

$$WF_{green} = 10\,\frac{\min(R_{eff}, ET_{\mathrm{cadj,i}})}{Yield} \qquad (1)$$

Information about sugarcane yield under full irrigation is limited in Brazil, given the predominance of rainfed crops. According to Doorenbos and Kassam[4] in the tropics and subtropics a yield range of 100-150 Mg/ha can be considered under irrigation. Based on data from studies performed in Brazil, the average sugarcane yield under full irrigation is 157 Mg/ha; however, these yields vary widely (97 - 256 Mg/ha) due mainly to the cultivar used. We selected an average irrigated yield (for cultivar RB867515) to represent the yield of plant cane under full irrigation for the WF calculation. In the suitable areas for sugarcane, the average reported yield under irrigation for is 140 Mg/ha.

The volume of freshwater abstracted from rivers, lakes, and aquifers is referred to as the blue WF (Equation 2) where WF_{blue} is the blue water footprint (m^3/t) and I_{rrg} is the total irrigation (mm).

$$WF_{blue} = 10\,\frac{I_{rrg}}{Yield} \qquad (2)$$

3. Results and discussion

The average WF for plant cane in Brazil is 103 m^3/Mg. Although Santa Catarina is the most efficient state in terms of WF (average of 78 m^3/Mg) only 0.3% (175,000 ha) of total suitable areas for sugarcane are located in this state (Fig. 1a and 2). The states of Ceará (120 m^3/Mg) and Rio Grande do Norte (116 m^3/Mg) have the highest average WFs for sugarcane production, and comprise only 0.3% of the total suitable areas for sugarcane. These trends indicate the reality of using multiple criteria to select regions for sugarcane production via the ZAE-Cana.

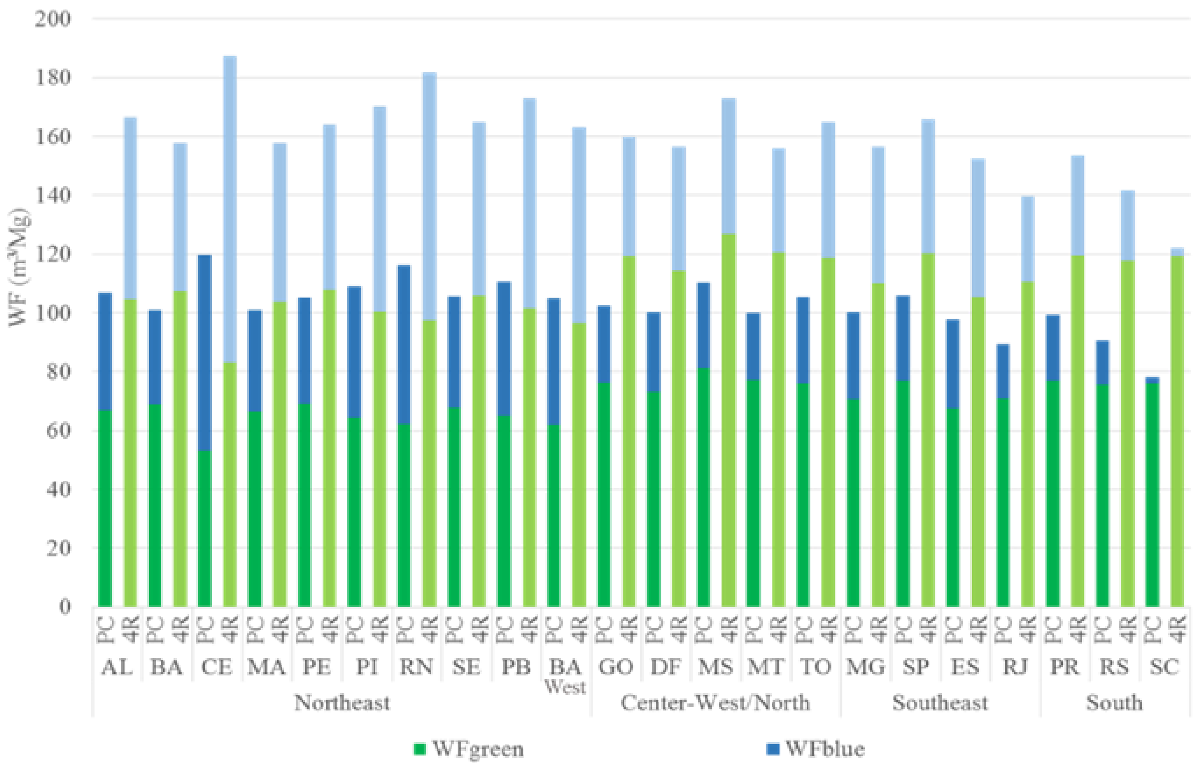

Figure 1: Green and blue water footprint among the states and regions considering plant cane (PC) and 4th ratoon (4R). States with higher fractions of blue WF indicate the need for irrigation to prevent yield reductions from water stress

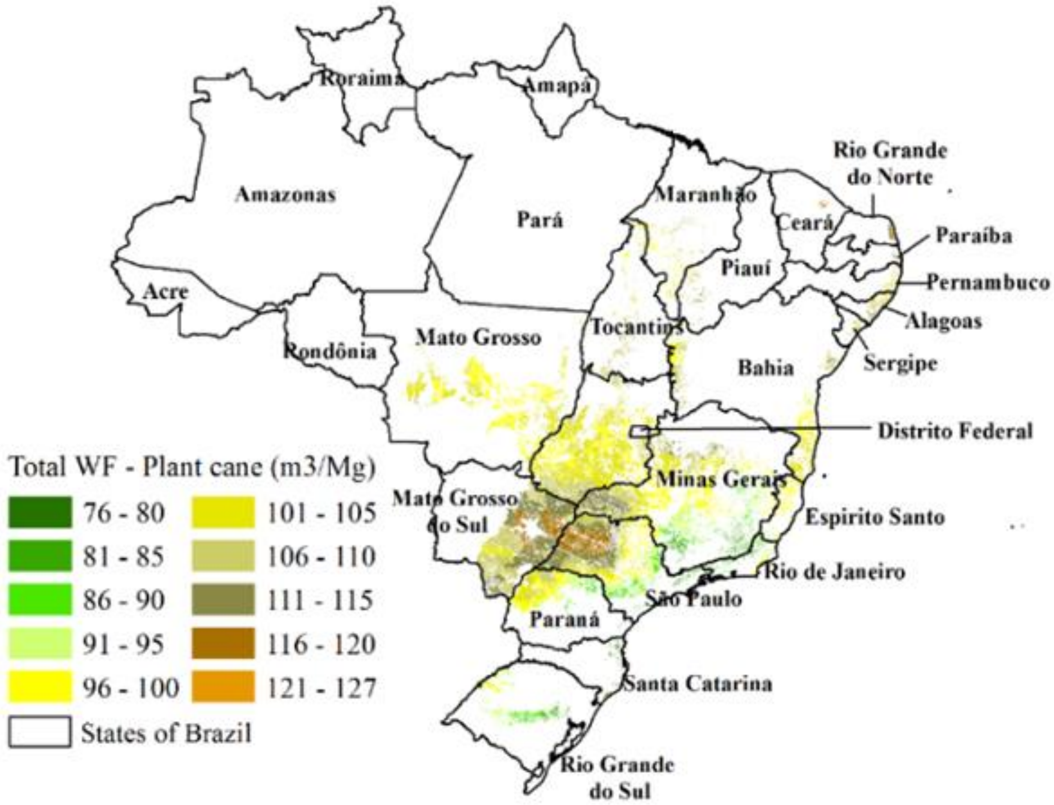

Figure 2a: Total water footprint of plant cane in the areas selected by Sugarcane Agroecological Zoning – Brazil

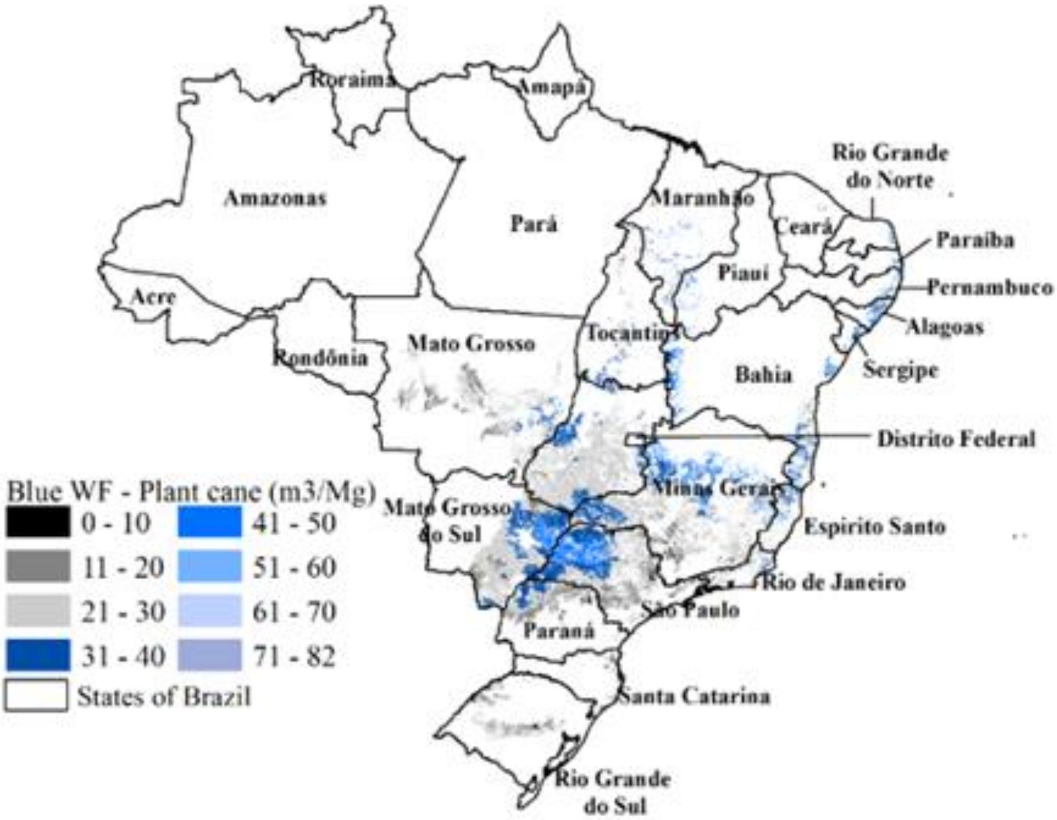

Figure 2b: Blue water footprint of plant cane in the areas selected by Sugarcane Agroecological Zoning – Brazil

Due to the intrinsic yield declines with increasing cane ratoons, the average WF for the 4th ratoon in Brazil increases to 161 m^3/Mg (122 m^3/Mg in Santa Catarina to 187 m^3/Mg in Ceará) (Fig. 1b). These values are below the weighted global average of the sugarcane WF (considering only green and blue WF), estimated by Mekonnen and Hoekstra[5] at 196 m^3/Mg. Thus, it is possible that the regions with relatively poor climate for sugarcane within Brazil are still relatively good when considered at the global scale.

The average water footprint for planted cane in Brazil has slightly increased since 1980 due solely to an increase in the blue water footprint (see Figure 3). As a result of the blue WF increasing over the last three decades over the scale of the entire Agro-ecological zones for sugarcane in Brazil, increased irrigation would have been required to maintain maximum yields across all zones.

Conclusions

Although Brazil has large potential areas for sugarcane production, 65 million ha, only ~15% of the suitable areas were occupied with cane in 2014. The sustainable expansion of sugarcane in these suitable areas could meet much of the future demand for energy, mainly ethanol and electricity. Analyzing potential sugarcane yield under rainfed condition (using only green water), yield reductions ≥50% are found in ~60% of the total suitable area. Even in traditional sugarcane producing areas, in the center-south of Brazil, yield reduction under rainfed conditions can exceed 40%, and irrigation (via blue water) can increase the yield. High precipitation variability throughout Brazil results in net irrigation requirements increasing from southern and southeastern Brazil (net irrigation ≤200 mm) toward to the Northeast (net irrigation ≥800 mm/cycle).

The average sugarcane total water footprint (WF) under full irrigation in Brazil is 103 m^3/Mg for plant cane and 161 m^3/Mg for the 4^{th} ratoon (assuming 36% lower yield relative to plant cane). Although Santa Catarina has land with the lowest WF (78.1 m^3/Mg), this land represents only 0.3% of total area suitable for sugarcane.

Policy and water sustainability implications

To assess the viability of sugarcane cultivation, and possibly irrigation, across the Agro-ecological Zones of Brazil, the water footprint can be a useful metric. Areas with a high value for the blue WF indicate a need for irrigation to maintain maximum crop yields for that region and climate which is inherently too dry (to some extent) for rainfed cultivation. Thus, if planting sugarcane in the areas with high blue WF, it is important to consider the effect on surface and groundwater resources in

Within the center-south region of Brazil the green WF constitutes >70% of the total WF and covers ~72% of the total suitable areas for sugarcane. Thus, rainfall is able to provide most of the water needs for sugarcane production in this region. In the Brazilian Northeast, where water scarcity is high, this green WF fraction decreases, which increases the importance of irrigation (blue water) in sugarcane cultivation.

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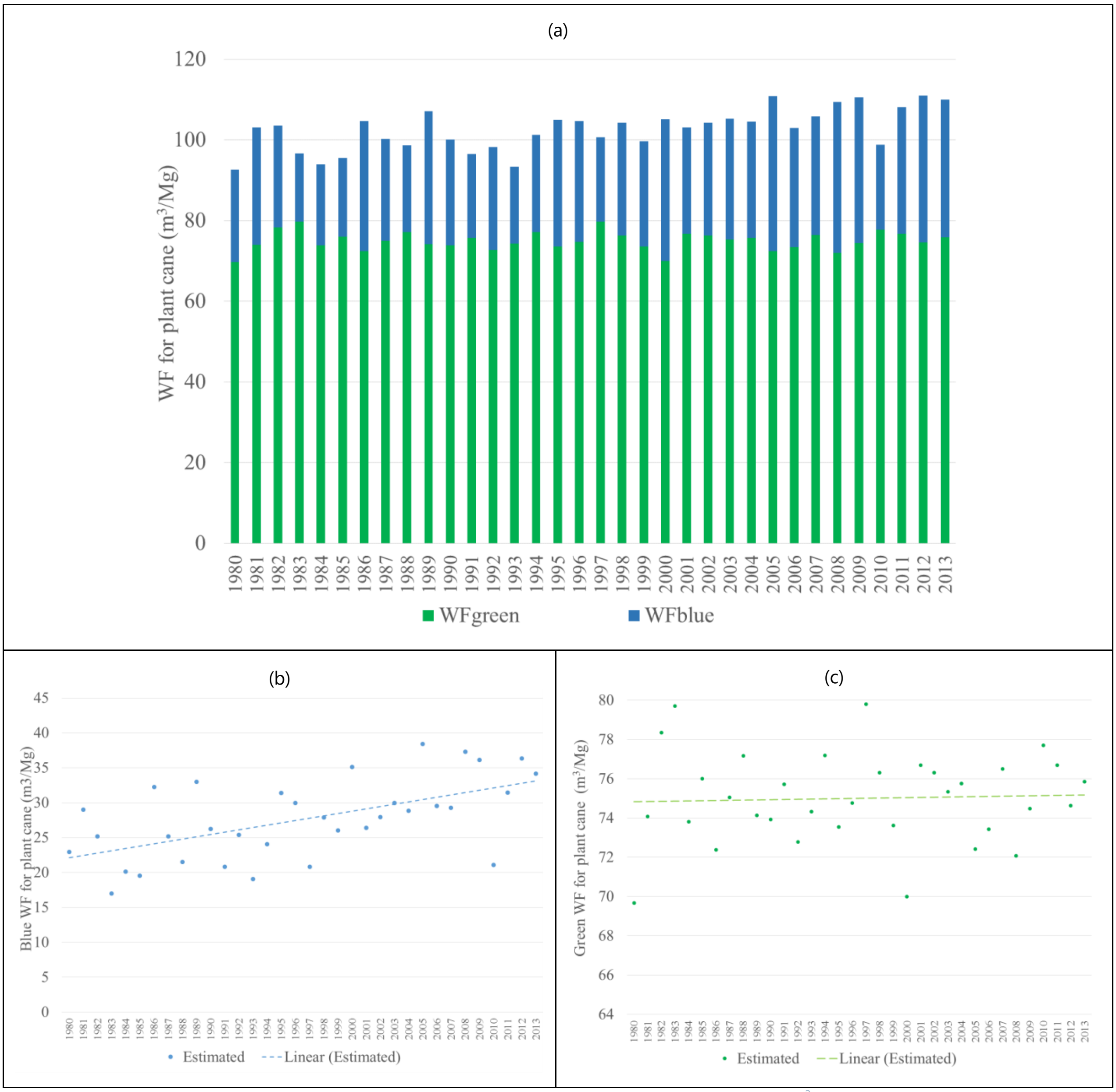

Figure 3: Green and blue water footprint variability in Brazil (overall), for the 1980-2013 base period[3], and the best fit linear regression between year and blue WF (b) and green WF (c).