Setting transformational pathways consistent with post-2015 SDGs: The case of Uruguay's rice sector.

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Abstract:

This research outlines the fundamental elements of a pathway for transforming Uruguay's rice sector in a way that is consistent with post-2015 SDGs. Uruguay is the most export-oriented rice producing country in the word, selling around 95% of its total production in the international market. This article introduces the methodologic approach followed for setting the productivity and environmental targets for 2030, which constitute the basis of the sustainable intensification process chosen by the country, and follows with the process of developing the transformation pathway that is necessary for achieving the goals. The simulated economic and environmental results are then presented and discussed in order to extract useful lessons for the development of SDGs in the case of other situations involving small open economies highly relying on agribusiness activities. This is precisely the reason why Uruguay was chosen as a relevant case study by United Nations, under the Sustainable Development Solutions Network initiative (SDSN).

Acknowledegment: The authors want thank all the stakeholders of the rice sector in Uruguay. for their strong support to this projetc and their commitment with the development of a sustainable transformation pathway for the national agriculture. Special recognition to ACA, GMA,OPYPA-MGAP and all the other institutions and persons that colleboratedI with this initiative. To our institution and to our colleagues at INIA, goe also our appreciation. All errors that could appear in this article are the sole responsibility of the authors..

JEL Codes: O33, Q01

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Keywords: SDSN, sustainable intensification, ATPi,
JEL codes: O13, O33, Q01

1. Background

1.1. Uruguay and the United Nation's Agricultural Transformation Pathways initiative

With the expiration of the Millennium Development Goals at the end of 2015, the international community agreed on an ambitious and transformational 2030 development agenda. The new set of Sustainable Development Goals (SDGs) and the concrete targets and indicators for achieving these goals are crucial frameworks to guide the global understanding of complex sustainable development challenges, to encourage actions and foster accountability. While these actions are global in scope, achieving these goals require concerted efforts at the country-level (SDSN, 2014). In other words, each country still needs to choose its own sustainable development path, with specific, achievable actions and outcomes at the national and sub-national levels.

By the end of 2013, Uruguay was selected as a pilot country, along with China and the United Kingdom, for a study case analysis of agricultural transformation pathways, under the United Nation's Sustainable Development Solutions Network initiative (SDSN). In 2014, the SDSN established an Agricultural Transformation Pathways Initiative (ATPi) in order of bringing together countries with a diverse set of agricultural contexts (Kanter *et al*., 2016). The ATPi focuses on developing, adapting and applying practical toolkits for countries to build, adopt and implement long-term policy roadmaps to achieve transformative changes in agriculture and food systems (Schwoob *et al*., 2016).

An international coordination team provided support in two important methodological areas: (i) developing realistic national and sub-national targets that are in line with the SDGs; and (ii) building technology and socio-economic roadmaps that enable countries to meet those targets. Each country had to implement its own methodological approach and particular toolkits, in in accordance with the reality of its own agriculture and food systems. However, there was a general framework linking all the study cases (Kanter *et al*., 2016). First, each country had to adopt a participatory approach, involving a range of key stakeholders from government, academia, industry and farmer organizations, making use of local tools and expertise. Second, the general methodology approach was based on the idea of "backcasting". According to this concept, targets are fixed at some point in the future, while pathways developed for achieving those targets are built by working backwards from that future point to the present (SDSN, 2015).

In the case of Uruguay, the development of SDGs would focus on the premise of "sustainable intensification" of its agricultural sector, which was defined as a strategic line by national authorities (MGAP, 2016). As a small economy, highly dependent on the export of agricultural products, Uruguay would be able to economically increase the productivity of its agriculture sector in a sustainable way, taking into account the social and environmental dimensions, as key factors.

The first study defined under the SDSN initiative the beef cattle production system (Kanter *et al*., 2016). However, Uruguay authorities doubled the bet by broadening the scope of the study and extending the efforts of setting up SDGs to other key sectors of agriculture that are relevant to its economy. This research article outlines the fundamental elements of a pathway for transforming Uruguay's rice sector, one of the selected sectors, in a way that is consistent with post-2015 SDGs. Uruguay is probably the most specialized export-oriented rice producing country in the world. Setting up an SDG for this sector is crucial for the Uruguayan economy.

First, this article introduces the methodologic approach for setting the productivity and environmental targets for 2030, which constitute the basis of the pathway, and follows with the process of developing the transformation pathway that is necessary for achieving the goals. The simulated economic and environmental results are then presented and discussed in order to extract useful lessons for the development of SDGs in the case of other situations involving small open economies highly relying on agribusiness activities. This is precisely the reason why Uruguay was chosen as a relevant case study by United Nations

1.2. Rice production in Uruguay: the baseline of the study

Uruguay is among the 10 largest rice net exporters in the world, so its production is intimately related to international markets. The productivity is also among the highest in the world (Table 1).

<TABLE 1>

The special position occupied by Uruguay in the rice world has been possible thanks to the continuous adoption of cutting-edge technology and cultivars selection carried out by the National Agricultural Research Institute or INIA, according to its Spanish acronym (*Instituto Nacional de Investigación Agropecuaria*). In the last five years, national average yield surpassed 8 metric tons per hectare (MT/ha) (DIEA-MGAP, 2016; 2017). Year 2014/15 set a historical record when the national average yield reached 8.69 MT/ha of paddy rice. In 2016/17, the figure was almost the same.

In 2015, the total agribusiness sector represented approximately 12% of Uruguayan GDP (6% from primary sector and 6% from agriculture manufacturing sector). Likewise, it represented more than 76% of the total money value of exported goods by the country. Uruguay exports more than 90% of national rice production, representing about 5% of total exports of goods (Saldías *et al.*, 2016). Rice exports only run behind cellulose pulp (22%), soybeans (18%), beef (17%), and dairy products (9%).

According to official custom´s data, in 2017, Uruguay exported 985 TMT of rice products, shipping weight, equivalent to approximately 1.4 million metric tons of paddy (MMT). Forty-five percent of the exported volume was shipped to South American destinations, mainly Peru and Brazil. The rest of the Americas and the Caribbean were the destination of 20.2%. Mexico and Cuba stood out as the main markets in this region. With Iraq and Iran as key markets, the Middle East absorbed 15% of the exported volume, while Europe and Africa accounted by 10.3% and 9.5% of the volume, respectively.

The history of the crop in Uruguay dates back to the end of XIX century, with references to experimental rice crops since 1869. However, consistent data exists since 1927, when rice milling firms established in the east region of the country (ACA, 2014). Table 2 shows different stages in the evolution of rice production in Uruguay.

<TABLE 2>

In 1946/47 crop season, the rice area surpassed for the first time 10 thousand hectares, with a total production of more than 35 thousand metric tons (TMT) of paddy. The area was doubled in 1962/63, with a production of 77 TMT in more than 20 thousand hectares. The 50 thousand hectares were surpassed in 1975/76. In the next three decades, from 1980/81 to 2010/11, the area devoted to rice grew 3.5 times while the average national yield grew at least 20%, each ten years.

The maximum area (206 thousand hectares) was recorded in the 1998/99 harvest. The rice area never reached 200 thousand hectares again, after. In the last six years (2011/12 to 2016/17), the area remained quite stable, even showing a slight decline, in the average of 167 thousand hectares. In the last four, the area barely attained 163 thousand hectares although the national yield largely surpassed 8 MT/ha. In 2016/17, Uruguay planted 164,457 ha, with a historical record production of 1,409,561 MT of paddy rice. The average yield was 8.57 MT/ha, the second highest productivity since 2014/15, when it achieved 8.69 MT/ha in 160,733 ha.

Rice is cultivated in three well-defined rice agro-ecosystems (Figure 1), mainly determined by soil types and the availability of water sources, since 100% of the area is developed under irrigation:

East region (Includes the departments of Treinta y Tres, Rocha, Lavalleja, Maldonado, and east of Cerro Largo: with around 100,000 ha planted every year, this region is characterized by plain and poorly drained soils, temperate climate, and risk of cold weather.

North region (departments of Artigas, Salto, and Paysandú): planting near 36,000 ha per year, this region is characterized by a hills topography, fertile soils, subtropical climate and very low risk of cold weather.

Center region (departments of Tacuarembó, Rivera, and west of Cerro Largo): plants something less than 33,000 ha; this region is characterized by having a great diversity of soils and its climatic conditions are similar to the East region.

<FIGURE 1>

The crop is mainly produced in rotation with pastures. This means that rice production is closely linked to livestock production. Sixty percent of the rice area is planted on natural grasslands or some type of return and the remaining 40% on rice stubble (Uruguay XXI, 2015). The yield would be affected after several cycles due to increasing weeds and soil compaction, which makes necessary the rotation of the crop. This rotation of rice with livestock implies that the total area in the system is three to four times the area planted every year. In addition, the rotation system reduces the impact of agrochemicals compared to continuous rice (Battello, 2007).

The predominant rice production system includes two consecutive seasons of rice followed by three years of perennial and annual pastures (mixes of grasses and legumes). The rice-pasture rotation system is considered more sustainable and productive than traditional monocrop systems, as it promotes the natural preservation and regeneration of the soil's physical properties and lowers the incidence of disease and prevalence of weeds and insects in rice production. Although, some farmers have changed their rotation patterns to incorporate soy production as an alternative summer crop in the last few years due to high soybean prices (Irisarri *et al*., 2012), rice-pasture systems are expected to remain the predominant rotation system. Therefore, an increasingly important opportunity for productivity gains may lay with mixed-crop and pasture rotation systems, which will be revealed in in-field experiments conducted by INIA.

There is still debate within the scientific community about what is the actual potential yield of rice in Uruguay, with the available technology. Irrigated crop yields are linearly correlated with the amount of solar radiation that the crops receive during critical development stages, particularly during panicle initiation. Pérez de Vida y Ramirez (2012) indicated that although potential yields in temperate climates may reach, in theory, as much as 15 MT/ha, actual radiation levels in Uruguay suggest that potential yield is probably much lower. Uruguay exhibits a level of variability in solar radiation that other high-yielding temperate regions do not have. This limits the ability of reaching full potential, even though the country still ranks in the top five list of countries with highest average yield (USDA-FAS, 2017).

Temperature has also been shown to be a critical factor; rice does not flower under the stress of low temperatures, and while there are some varieties that can tolerate low temperatures, none of the varieties adapted for use in Uruguay thrive under those conditions.

Sowing date is particularly important to determine rice yields. There is a significant association between optimal planting times and higher yields, with a yield difference of almost 1.5 t/ha between early and late planting (Pérez de Vida y Ramirez, 2012). Similar results were found by Carracelas *et al*. (2016). October 15th is generally accepted as a key date. Under normal conditions, planting earlier than October 15th results in greater yields than after that date (Pérez de Vida, 2010; Macedo, 2014).

Rice growers are aware of the optimal planting time even though they often cannot comply because of adverse weather conditions, or issues with land preparation. Ideally, they should begin preparing the land for planting as early as June, which often conflicts with the grazing schedule of livestock in pastures rotating with rice. The majority of rice producers (70%) do not own the land they cultivate or the water they use, and this complicates their ability to follow suggested best practices for planting. Given the aforementioned difficulties, the best strategy may be to consider an optimal planting window for each production zone instead of particular dates, to control for potential micro-climate differences across the three geographic zones.

Only few rice varieties are used in Uruguay and most of them have been generated by INIA, through an integrated and strong national breeding program that evaluates and develops new cultivars. This confirms the relevance of research in the generation and transfer of technology for rice production, which has allowed the evolution of this culture. It is also important to mention that, in Uruguay, all the seed used must be certified. The release of a new variety is agreed by a technical committee with participation of INIA researchers, growers and millers.

The relevant stakeholders of the rice sector have historically been very involved in the production process. There is a high degree of coordination between growers and millers for making technological and market decisions. An example is the pricing system that defines the price paid by the miller to the farmer for its grain. For more than half a century, this price has been set up through a private agreement between the national rice growers association, ACA (*Asociación de Cultivadores de Arroz*) and the miller's guild, GMA (*Gremial de Molinos Arroceros*), which nucleates the three largest mills (SAMAN, Casarone and Glencore), and Coopar. The latter is independent and constitutes the fourth largest mill. Together, these four mills represent three quarters of Uruguay rice exports. In turn, ACA represents between 85 and 90% of total rice growers.

In 2013, the rice sector launched the GBPA (*Guía de Buenas Prácticas Agrícolas en el Cultivo de Arroz*), a guide of good agricultural practices, with the objective of guiding farmers, agronomists, and workers of the sector with general recommendations and available know-how for a sustainable rice production, in order of assuring the greatest possible productivity while bolstering up the competitiveness at both national and international level. The GBPA was the outcome of a coordinated effort between ACA, GMA, and INIA, along with the school of Agronomy of the *Universidad de la República* (UDELAR) and the Laboratorio Tecnológico del Uruguay (LATU).

Facing the challenge of diversifying rice exports among different destinations, the GBPA was seen as a contribution to the differentiation of Uruguayan rice trying to make easier the access to markets that are willing to pay more for a product with environmental added value. For example, in Uruguay less agrochemicals are used in rice cultivation than in other countries. This characteristic differentiates Uruguayan rice in international markets (García-Suárez *et al*., 2012).

The public sector only has a minimum participation in the rice agribusiness. There are no interference in the prices, no subsidies to production or marketing, and the pricing system completely works as a private agreement. Its participation is restricted to the *Comisión Sectorial del Arroz* (CSA), a space of work and consultation for the different institutions involved in the rice sector. Created by law in 1973, the main objective of the CSA is advising the government on issues related to rice production, supply, industrialization, marketing, export, land tenure, irrigation, and dams, among other related aspects. A second objective is developing guidelines for the promotion of technology adoption and expansion of rice production through the use of irrigation, fertilization and practice of appropriate rotations, as well as making recommendations with regard to land and water policy concerning the expansion and cultivation of rice.

2. Data and Methods

2.1. General aspects and backcasting approach

As with the other sectors included in the Uruguay case of the SDSN project and the ATP initiative, the general framework adopted with the rice study was the "backcasting" approach (SDSN, 2015), adapted to the local conditions. As explained by Kanter *et al.* (2016) in occasion of the beef study also from the Uruguay case, the backcasting sets targets at a future date based on ex-pert judgment, best available technologies and other factors, with technical pathways subsequently developed for achieving those targets by working backwards in time towards the present. In contrast to forecasting, which allows developing multiple futures from a common present, the “backcating” develops pathways to a single desired future, making it a more relevant tool for policy planning. In other words, forecasting explores what could happen, while backcasting articulates what might be a pathway to a desirable future. The latter is very much a problem-solving approach, as it enables users to set priorities, rank solutions and identify the steps that need to be taken (and when) in order to reach a desired outcome.

Sustainable intensification of Uruguay’s rice sector is a multi-objective optimization problem: the challenge is to maximize productivity and farmer’s income while maintaining the high standards of grain quality that characterize Uruguay rice, and minimizing a suite of environmental impacts (greenhouse gas emissions, biodiversity loss, water footprint, nutrient loss, etc.). The use of a unique method to solve this complex problem would probably lack of the necessary flexibility. Instead, a mixed-methods approach was adopted for this project, blending modeling efforts with expert judgment from scientists and academics, as well as representatives from the public and private sector.

2.2. Research team and stakeholders participation

As pointed out by Kanter *et al*. (2016), Uruguay is a unique case in that there is a strong culture of collaboration and coordination among agricultural stakeholders, which was present prior to the ATP initiative. Building a team and executing the research study in a comprehensive and multidisciplinary way and with a strong involvement of stakeholders was a relatively easy task. The core team leading the study was composed by researchers of INIA, ACA, OPYPA, which is the policy and planning office of the Ministry of Agriculture (*Oficina de Programación y Política Agropecuaria*) and the Uruguayan office of Columbia University’s International Research Institute for Climate and Society (IRI). Other academic industry and farmer stake- holders were involved at different stages of the project via informal consultation and stakeholder workshops.

2.3. Setting the baseline and productivity target

Since the very first beginning, the definition of sustainable development targets for the rice sector involved all actors in the rice production chain as much as possible through in-person consultations, intensive literature reviews, and frequent updates on our progress. One important consideration for setting a productivity target was that it should not sacrifice the high industrial performance, the good culinary quality of the grain, as well as any other desired characteristic exhibited by the varieties currently in use, for the sake of potentially higher yields.

For instance, GMO rice will not be grown in the country (García-Suárez *et al*., 2012). However, there is a possibility that this could change in the near future. Significant work is being done on hybrids that could increase yields. Those hybrids currently produce rice of substandard culinary quality, and thus have not been widely adopted. Experts asked about this matter indicated that if the quality issues can be resolved, though, hybrids might be used by a significant percentage of producers (Zorrilla, 2015).

The baseline or actual yield (Ay) was defined for year 2015, as the average yield obtained at national level over the past five years (2011/12 to 2015/16). The theoretical potential yield (TPy) was defined as the yield obtained from crop models that, in theory, are only limited by radiation and temperature. The TPy was estimated using the ORYZA V3 model (IRRI, 2015). It was calibrated and validated for the Uruguayan conditions (Carracelas *et al*., 2016), using 25-year data of two cultivars, cultivated in six locations on three different planting dates.

The model addresses both the crop management and the environmental factors (i.e. water and nutrient limitations, climate, disease, weeds, and contaminants) and the change in average yield in order to better project potential yield with no limitations in inputs. The goal was simulating potential yields to define the exploitable yield gap, in order to understand the growth possibilities for the sector in the three main rice producing regions of Uruguay (East, North, and Center).

It was assumed that about 80% of maximum experimental yields (yields realized during field experiment with no nutrient or water limitations, and with no pests or disease impacts) can be realized commercially (Deambrosi *et al.*, 2016; Carracelas *et al.*, 2016). Thus, a realistically expected exploitable yield (Ey) was determined as Ey = 80% TPy. The difference between the exploitable yield and the actual yield is the exploitable yield gap (Gy = Ey – Ay)

The timeframe for attaining the target was 15 years (2015-2030). Focusing on closing the exploitable gap at the national level, the productivity target (Ty) for the rice sector by 2030 was defining as the yield that needs to be achieved in order to reduce Gy by 50%, that is: Ty = Ay + ½(Gy)

2.4. The sustainable development pathways

After setting the productive targets and assessing its consistency, the next step was developing the sustainable pathways that should lead to them. Two approaches were defined in order to attain the productive target as the national average by 2030: "breaking the ceiling", that is, move the best producers (percentile 10) to a new position by achieving yields higher than what is considered biophysically possible today, and "closing the gap" by bringing the current average yields to the best commercial yields obtained today by the best producers.

In order to do this, INIA's National Rice Program carried out a project named "Breaking the ceiling" (Deambrosi *et al.*, 2016). In the first step, the project identified the most common set of management practices applied by a group of rice producers (superior 5-quantile) currently obtaining the higher yields in Uruguay. These farmers were already achieving yields very similar to the 2030 productivity target with the best use of the available technology, up to this moment. From this result, the idea was developing a pathway that could turn the management practices these farmers applied today into the most common set of practices applied in 2030.

In the second step, the objective was the generation of changes in technology use and crop management practices aiming to increase commercial yields by at least 10% with respect to the yields obtained by the best producers (Deambrosi *et al*., 2016). Those changes will be driven mostly through the adoption of new technologies, as well as the integration of higher-yielding varieties.

2.5. Economic Analysis

The economic feasibility analysis of the sustainable intensification process towards 2030 followed the methodology steps described by Ferraro *et al*. (2015) and Saldías *et al*. (2016). The analysis took into account the 2030 target and the technological alternatives proposed to achieve this desired productivity level. The results were compared with those previously obtained for the baseline. The analysis was performed considering the whole rice chain, from the field, where the cereal is produced, to the sea port, when the rice products are ready for export. This allowed assessing the potential economic gains of the sector from the process of sustainable intensification, and compare them with the baseline.

The basic analytic tool was the Policy Analysis Matrix (PAM) developed by Monke and Pearson (1989), with the adaptations proposed by Rava *et al*. (2011). The PAM is an instrument designed to assess the competitiveness of industrial supply chains. It has been widely used in numerous studies in Brazil (Vieira *et al*., 2001; Lopes *et al*., 2012; Souza *et al*., 2017), Costa Rica (Jimenez and Quiros, 1999; Charpantier and Mora, 1999), Spain (Reig *et al*., 2008), and Uruguay (Rava *et al*. 2011, 2012; Ferraro *et al*., 2017).

2.6. Environmental factors

The significant increases in total national production derived from agronomic improvements and high-yielding locally-developed varieties did not represent negative environmental consequences, mostly due to some characteristics of rice production in Uruguay such as the rotation with perennial pastures (Pittelkow *et al.*, 2016).

Aiming at analyzing the sustainability of rice intensification in Uruguay, Pittelkow *et al.* (2016) estimated a set of sustainability indicators from 1993 to 2013 and assessed synergies and tradeoffs due to changes in management practices. The set of estimated indicators were: land use and crop productivity, resource use efficiencies (energy, nitrogen, water) and environmental impacts (N loss, carbon footprint, agrochemical contamination risk). This methodological framework developed by Pittelkow *et al.* (2016) was used in this research to calculate the same set of environmental indicators for both the baseline (2015) and the target (2030) scenarios. For the latter, the simulations were run with the management practices described by Deambrosi *et al.* (2016).

3. Results and Discussion

3.1. Results

A summary of the parameters and values used to determine the 2015 baseline and the 2030 target in presented in Table 3

<TABLE 3>

The actual yield (Ay) was estimated at 8.1 MT/ha. Defined as the 2015 baseline, it is the average yield obtained at national level over the past five years (2011/12 to 2015/16). The Theoretical potential yield (Tpy) was obtained by simulation with the ORYZA V3 model. The results are depicted in Figure 2. The average value was set at 14.0 MT/ha, with a maximum of 16.6 MT/ha and a minimum of 11.3 MT/ha. The model was run for a period of 18 years (1997-2014), with data of 7 meteorological stations.

<FIGURE 2>

According to Carracelas *et al.* (2016), the expected exploitable yield was estimated as:

(1) Ey = 80% TPy = 11.2 MT/ha

Thus, the exploitable yield gap was calculated as:

(2) $Gy = Ey - Ay = 3.1$ MT/ha

Closing by 50% the exploitable gap at the national level, the productivity target (Ty) for the rice sector by 2030 was calculated as:

(3) $Ty = Ay + \frac{1}{2}Gy = 9.65 \cong 9.7$ MT/ha

The consistency of the proposed target was verified through the analysis of production information provided by GMA from the last five harvests (2010/11 to 2014/15). The objective was evaluating the feasibility of achieving the proposed productivity level by 2030, looking at the proportion of rice growers that already reach this target with the currently available technology. On average, about 10% of the rice growers already reached the productive target with the currently available technology. Figure 4 depicts the cumulative distribution of yields for 2001/02 and from 2010/11 to 2014/15.

<FIGURE 4>

Figure 5 compares the evolution of the national average yield and the average yield of the best 10% producers, suggesting that the objective is achievable despite the important challenge of bringing the national average to these values. There was a consensus among consulted experts that the methodological framework and the values used in the estimation were adequate.

<FIGURE 5>

Table 4 summarizes the results of comparing the SDGs proposed by 2030, in terms of productivity, economic outcome, and environmental targets, with the prevailing situation in 2015 (baseline). The first column heading describe the measured variable, the second set the 2015 baseline values; the third column shows the 2030 target values, and fourth one shows the variation between target and baseline values.

<TABLE 4>

The first row compares the 2030 productivity target against the 2015 baseline, in metric tons per hectare (MT/ha). Engaging the rice sector in the proposed sustainable intensification pathway would allow increasing national average productivity by almost 20%, from 8.1 to 9.7 MT/ha. As shown in the next three rows, income, costs, and profits per hectare are measured in terms of 50-kilo bags[1]. Income is about to rise in the same proportion than yields. Considering USD 10.25 per bag (≈ USD/MT 205), which was the final agreed price for 2015/16 harvest, total costs are expected to rise, on average, from 160 to 177 bags/ha (10.6%). Net profits would multiply by 7.5, growing from 2 bags/ha (baseline) to 17 bags/ha (target).

The remaining rows list the set of environmental indicators considered in this study, whose detailed explanation and estimation was detailed by Pittelkow *et al*. (2016).

a. Energy indicators:

   - Net energy consumption: balance between diesel consumption in field operations (tillage, sowing, fertilization, agrochemicals application and harvesting); the embodied energy in inputs (seeds, fertilizers and agrochemicals), and diesel and electricity used for irrigation.
   - Net energy yield: subtraction between the energy output in the form of grain and the net energy consumption.

b. Water productivity: relationship between grain yield per hectare and total water consumed (irrigation water + rainfall).

c. GHG Emissions:

   - Emissions per hectare: calculated based on the study carried out by MGAP-FAGRO-INIA-LATU (First study of the carbon footprint of three agro-export chains: beef, dairy and rice), which included field emissions and transport of Inputs and production.

[1] Paddy rice is usually packed in 50-bags. Rice growers find extremely useful this measure when talking to production, yields, some input costs (land and water). For that reason, income, costs, and profits were expressed in that way in Table 4.

- Carbon footprint: relationship between emissions per hectare and productivity.

4. Nitrogen:

- N use: N applied per hectare.
- N use efficiency: relationship between productivity and applied N.
- N loss: estimated based on experimental results indicating that 52% of the applied N is recovered by the crop and the rest is lost (Castillo *et al*., 2015).

The spider diagram in Figure 6 illustrates the changes in productivity and environmental variables between the 2015 baseline (index = 100) and the 2030 target. An additional data set was included in the comparison, considering the Top East producers (TE), whose yields were currently around the 2030 productivity target.

<FIGURE 6>

The results show that total energy consumption per hectare was 7% higher for TE producers. Although energy for irrigation decreased 13% in TE producers, the increase of diesel in field operations (+15%) and embodied energy in inputs (+8%) explain the increase in total energy consumption. Because of the higher yields achieved by the TE producers, total energy output rose 14% and net energy yield went up 15.2%.

Energy consumption for the rice sector has been declining roughly 19% from 1993/94, with the largest drop occurring around 2002/03. This was due largely to a rapid shift to reduced tillage systems and a switch in irrigation systems from diesel to more efficient electric systems. This drop, combined with increasing yields during the same period, led to an increased net energy yield of around 41% since then (Pittelkow *et al*., 2016).

The total available water productivity (kg/m^3) was 13.9% and 22.6% higher in the TP group and in the 2030 target scenario, respectively, due to the increase in productivity. This indicator considers the same amount of irrigation water for the three different scenarios, which means that the difference was explained only by the increase in yield (Pittelkow *et al*., 2016).

In turn, intermittent irrigation systems may significantly improve water productivity, although the degree of improvement depends on the production region. The amount of water required for rice production also depends on soil type and climate, which changes depending on the production region in question and can vary substantially from year to year (Carracelas *et al*., 2016).

Carbon footprint, as mentioned by Pittelkow *et al*. (2016), was estimated applying methods adapted from Becoña *et al*. (2013). The emissions (kg CO_2 eq/ha) were almost the same for the baseline, the TE and the 2030 target scenarios. However, when considering the yield-scaled carbon footprint, the emission declines 10.9% for the TP group and 17.3% for the 2030 target.

Nitrogen use (kg/ha) increases 8.4% with both TE and 2030 scenario, as increasing productivity takes more nitrogen. Crop yields and N application rates did not increase at a similar rate, as suggested by the values of N use efficiency, which grows 5.2% for the TE group and 13.2% in the 2030 scenario respectively. Nitrogen losses (kg/ha) were calculated using a fixed recovery rate for Uruguayan conditions (Castillo *et al*., 2015).

It is worth to highlight the concept of nitrogen use efficiency. Without real improvements in N use efficiency, the increasing trend observed in the application of N fertilizers would be one of the greatest threats to the rice sector's environmental indicators, especially given that, with subsequent additions of N, yields will likely increase at decreasing rates. Between 1994 and 2015, nitrogen use increased from 45 kg N/ha to 80 kg N/ha (Pittelkow *et al*., 2016). Such increase corresponded with the highest rate of annual yield increase in history (150 kg/ha/year), achieved despite the relatively small amount of N/ha (Zorrilla, 2015).

A pertinent question to consider here, though, is N balance. A yield of 8 MT/ha of rice is equivalent to roughly 16 MT of total rice biomass. At 1% N content, that equals 160 kg

N/ha in the biomass. Therefore, a target close to 10 MT/ha will be equivalent to 20 MT of total biomass/ha or 200 kg N/ha. Uruguayan producers use 80 kg N/ha with efficiency levels that are rarely above 30-40%, meaning that the crop only receives 30 kg N/ha from fertilizers. The rest of the N used by the plant comes from the soil. Careful consideration must therefore must be given to whether the best strategy should be on lowering fertilizer rates or on obtaining a higher N use efficiency rates.

3.2. Discussion

The ultimate goal of this project was to define pathways for the sustainable intensification of the rice sector in Uruguay that could be attractive to all relevant stakeholders, and thereby able to be implemented. After analyzing all aspects of the rice production system, comparing the practices of the best producers versus the least efficient producers, and extensive consultations with leading representatives of all of stakeholders, a preliminary set of overarching recommended strategies for Uruguay's sustainable intensification of rice have been defined.

Under these overarching strategies, recommendations of different methods to achieve the suggested pathways that stakeholders can implement to reach the goals set forth in this report were provided. These strategies aimed to be attractive to all stakeholders, in order to ensure that that this work could overcome the framework of a theoretical experiment to become a feasible realistic pathway.

Closing the exploitable gap by 1.55 MT/ha would be done largely by transferring the most efficient practices to farmers who currently operate inefficiently. These practices include an optimal planting schedule, the adoption of the best-adapted varieties, use of proper planting techniques, and a more efficient use of inputs. That being said, it is important to recognize that not all of the factors that affect productivity can be entirely controlled by the farmers themselves (i.e., international market prices or farmer's timely access to land and water for irrigation due to crop rotation practices). It is also acknowledged that the proposed pathways must include solutions that incorporate all links of the production chain, including government policies, to address these fundamental concerns.

The preliminary overarching recommended strategies for Uruguay's sustainable intensification of rice are presented below.

3.2.1. Transferring best practices to less efficient producers

As it was described previously, a set of management practices was identified by Deambrosi *et al*. (2016) for a group of producers currently achieving the best yields. As expected, this set of management practices showed an improvement in the efficiency indicators associated with an increase in productivity. These practices can be considered as guidelines for increasing productivity with environmental sustainability.

However, there are farmers currently applying similar technologies that reach lower yields; in turn, there are rice producers obtaining higher yields by applying a different set of management practices. In addition, the set of management practices applied by the top and the lower yielding farmers are very similar. The timing for doing actions as well as the administration and management skills of individuals were identified as the main differences among them (Zorrilla, 2015).

In this sense, ACA is conducting a study to understand how the general practices included in the GBPA can be better tailored to the needs of producers, so that its recommendations are more abundantly implemented. While most producers know the existence of the document, few of them implement the document's recommendations (Sanguinetti, *personal communication*).

3.2.2. Work out land leasing contracts to allow growers planting within the optimal window

The market-side of the rice system works in an integrated manner and particularly well. Although rice producers are aware of the optimal planting time, the majority (70%) do not own the land they cultivate or the water they use. Additionally, the rice production system in Uruguay includes the rotation with pastures. Thus, following the recommended practice of planting in a timely manner is sometimes a complex task.

This is reflected, for example, by the fact that farmers should begin land preparation for planting as early as June, which often conflicts with the grazing schedule of livestock in pastures rotating with rice. Any proposal to increase rice productivity will need to address these issues. An option could be to engage the landowners, usually beef producers, in conversations to think of novel ways to create a win-win relationship that mitigates risk and improves efficiency for all parties.

3.2.2. Public policies to incentive a more responsible energy and water use

This is reflected, for example, by the fact that farmers should begin land preparation for planting as early as June, which often conflicts with the grazing schedule of livestock in pastures rotating with rice. Any proposal to increase rice productivity will need to address these issues. An option could be to engage the landowners, usually beef producers, in conversations to think of novel ways to create a win-win relationship that mitigates risk and improves efficiency for all parties.

Consultations with ACA led to the conclusion that greatest challenges for rice producers in Uruguay are market price volatility and high production costs. Many of the production costs are related to government policies and regulation. Over the last ten years, the sustained increase in production costs of (diesel oil, electricity, water, and labor, including social security charges) has not been accompanied by price adjustments, thereby reducing crop net income. Ferraro *et al*., (2017) argued that this has affected not only the profitability of the business itself but also the traditional contribution capacity of the sector to the rest of the economy. While production costs have increased at an average annual rate of 7%, the price received by producers has only increased at 4% per year, during the same period.

For instance, rice growers are currently charged for water usage based on the number of hectares that will be irrigated rather than the actual water used. Thus, they have no incentive to better manage or monitor their water usage. Similarly, the power company, which is publicly owned, charges a "peak hours" rate, meaning that farmers currently work to undertake their most energy intensive practices at non-peak hours. This can negatively affect productivity as well as limit water and nutrient efficiency. ACA is currently negotiating with UTE (Uruguay's Electric Company) on a proposal to charge a standard, lower fee during irrigation times. If this is accomplished, the cost structure could change significantly for rice producers.

3.2.3. Research agenda: more efficient and productive hybrids and varieties,

INIA is conducting significant work on the development of new varieties and hybrids with the objective of increasing yields and/or reducing the amount of inputs. An issue with currently available hybrids is that they produce a type of rice with lower industrial quality. If that issue is resolved, up to 30-40% of the rice area could be sown with new more productive high-quality hybrids. INIA already has some promising lines and biotypes under evaluation, which go in that direction. A key issue for the introduction of new hybrids and variables is the development of materials allowing higher yields while lowering carbon footprint.

4. Conclusions

The results presented in this article correspond to a multidisciplinary and multi-stakeholder project. The objectives are far more ambitious than just producing good results from an academic point of view and feeding scientific discussion. They go far beyond, with the pretention of making a solid contribution to the construction of challenging but realistic transformation pathways for Uruguay rice sector. For this reason, all the relevant stakeholders (growers, millers, researchers, scientists, policy-makers) were included in the discussion and implementation of steps and actions carried under this project, from the beginning.

At this point, the rice sector has defined the productivity target for a sustainable intensification of rice agribusiness. It has been evaluated from both economic and environmental point of view, and the outcome is promising. The social dimension was not directly addressed at this point although it has been always part of the discussion with the farmers. A specific study will likely be included in the near future. But the project is no over. More actions have still to be done to ensure the success of this important effort:

- Reaching a final agreement on the development pathway to be followed by the whole sector, in a way that makes sense for all parties.
- Redirecting research efforts on some specific issues like biodiversity and nutrient contamination in water as well as further studies regarding environmental impacts of rice production.
- Deepening regional studies on rice production (i.e.: the difference in soil types in the center, north and east, and how that affects drainage; climate).
- Working with the beef industry to promote more "win-win" relationships in livestock-rice systems.
- Engaging stakeholders in working out financial mechanisms for shifting to more efficient irrigation practices and crop management, in general.
- Leveraging the public and private agricultural extension services, with participation of GMA and ACA on supporting rice producers to use practices that result in improved profit margins that are also more environmentally sustainable.
- Gauging the feasibility of incorporating climate forecasts into annual projections
- Discussing mechanisms to study and forecast potential impacts of climate change on the various Uruguayan agricultural sectors.

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Table 1. Country's top-10 list of net rice exports and rice productivity (Year 2016).

Net Exports (TMT) (1)			**National Average Yields (MT/ha) (2)**	
India	10,210		Australia	10.21
Thailand	9,200		United States	8.40
Vietnam	5,400		**Uruguay**	**8.10**
Pakistan	4,200		Turkey	7.61
United States	3,420		South Korea	7.19
Myanmar	1,200		Argentina	7.00
Uruguay	**930**		China	6.90
Cambodia	900		Japan	6.82
Brazil	600		European Union	6.71
Argentina	560		Taiwan	6.28

(1) Thousand Metric Tons, shipping weight; (2) Metric Tons per hectare, paddy weight.

Source: Based on USDA-FAS (2017).

Table 2. Rice in Uruguay: evolution of area, production, and average yields.

Period	Years	Average Area		Average Production		Average Yields [1]	
		ha	Variation	MT	Variation	MT/ha	Variation
30/31-40/45	15	3,970	---	12,890	---	3.17	---
45/46-65/66	20	17,110	331%	54,900	326%	3.24	2%
66/67-80/81	15	45,850	168%	183,910	235%	3.96	22%
81/82-90/91	10	84,220	84%	408,100	122%	4.85	23%
91/92-00/01	10	157,490	87%	926,360	127%	5.82	20%
01/02-10/11	10	170,830	8%	1,218,960	32%	7.11	22%
11/12-16/17	6	166,720	-2%	1,360,340	12%	8.17	2%

[1] MT/ha: metric tons, paddy rice, healthy, dry and clean.

Source: Based on ACA (2017) and DIEA-MGAP (2017).

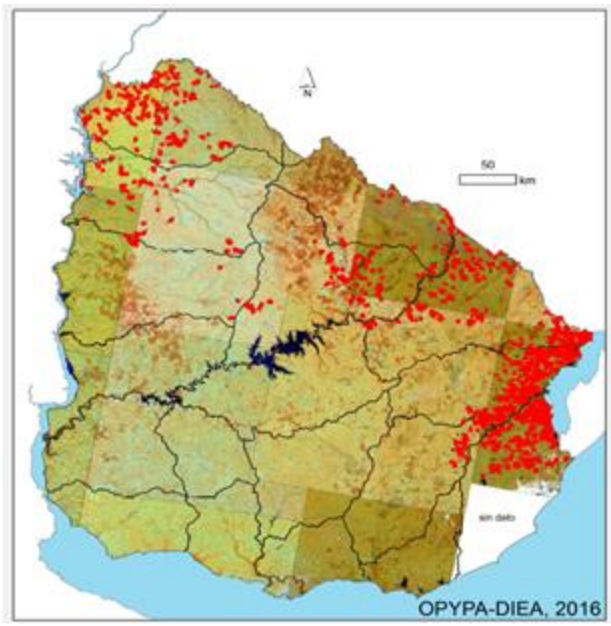
Table 3. Estimation of 2015 baseline and 2030 productivity target.

Parameter	MT/ha	Calculus	Source
Theoretical potential yield (Tpy)	14.0	Simulation	Carracelas *et al*. (2016)
Exploitable yield (Ey)	11.2	80% Tpy	Carracelas *et al*. (2016)
2015 baseline - Actual yield (Ay)	8.1	5-y Aver.	DIEA-MGAP (2015, 2016)
Exploitable yield gap (Gy)	3.1	Ey – Ay	
Target 2030	9.7	Ay + ½Gy	

Table 4. Comparison of 2015 baseline values and 2030 target values.

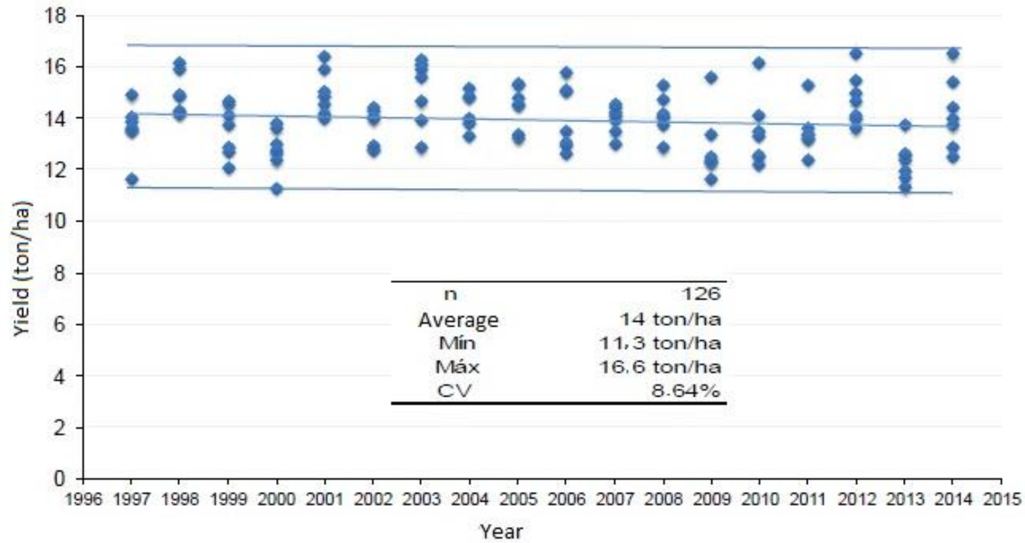
Variables	Baseline	Target	Variation
Productivity Variable			
National average yield (MT / ha)	8.1	9.7	19.8%
Economic Variables			
Income (50-kilo bags[(1)] of paddy / ha)	162	194	19.8%
Total Costs (50-kilo bags[(1)] of paddy / ha)	160	177	10.6%
Profits (50-kilo bags[(1)] of paddy / ha)	2	17	750.0%
Environmental Variables			
Net energy consumption (GJoules / ha)	17	18	7.0%
Net energy yield (GJoules / ha)	103	119	15.2%
Total available water productivity (kg yield / m^3)	0.62	0.76	22.6%
Total emissions (kg CO_2 eq / ha)	7,524	7,663	1.8%
Yield-scaled C footprint (kg CO_2 eq / mg grain)	955	790	-17.3%
Total Nitrogen use (kg N / ha)	65	70	8.4%
Nitrogen use efficiency (kg yield / kg N applied)	122	138	13.2%
Nitrogen loss (kg N / ha)	31	34	8.4%

[(1)] Income, costs and profits can be expressed in terms of production, i.e. "bags per hectare", as paddy rice is commonly packed in 25-kilo bags.



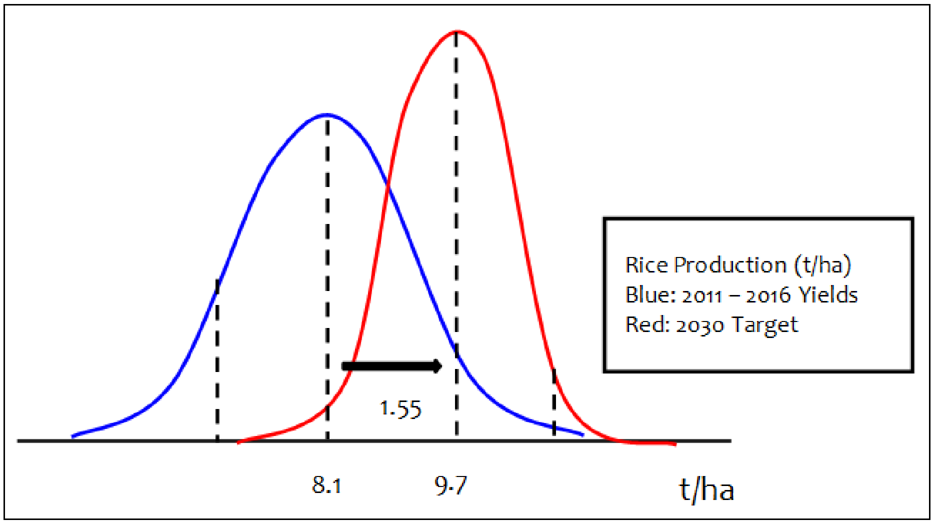
Source: Based on LANDSAT-8 and RESOURCESAT images.

Figure 1. Geographic location of rice production in Uruguay.



Source: Carracelas et al. (2016).

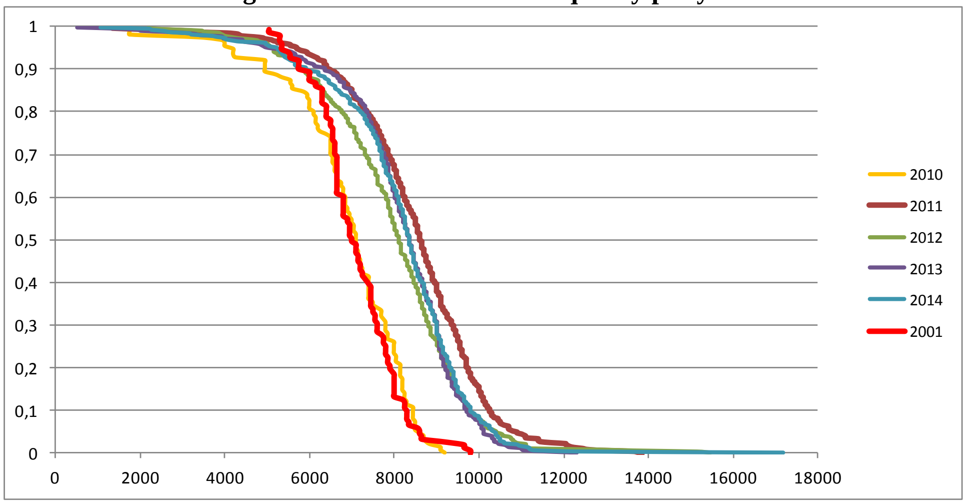
Figure 2. Simulation results of theoretical potential rice yields in Uruguay.



Source: Carracelas et al. (2016).

Figure 3. 2015 baseline, 2030 target and exploitable gap yield

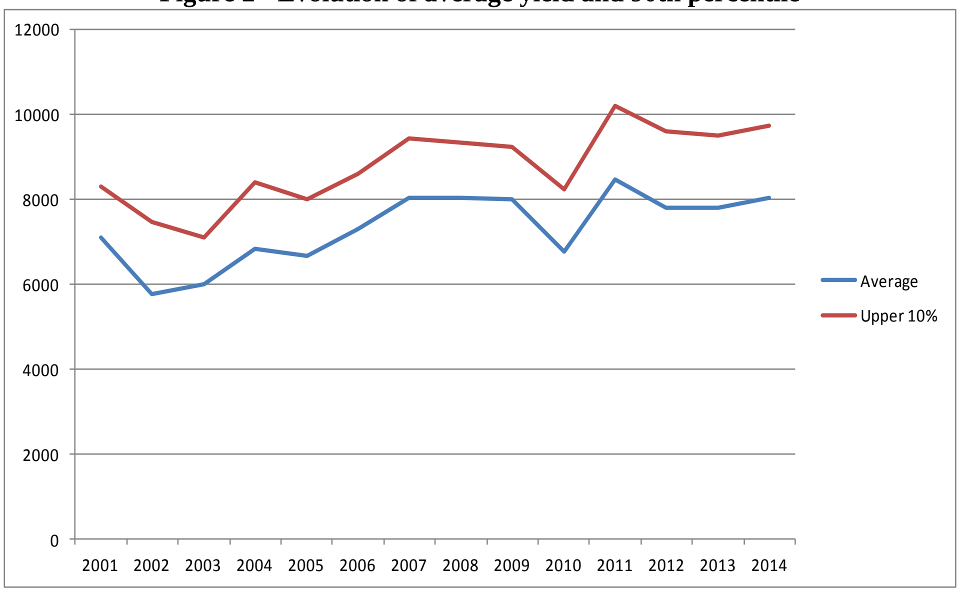
Figure 1 – Rice cumulative frequency per year



Source: SAMAN, Coopar, and Casarone data, BigData workshop, INIA, 2015.

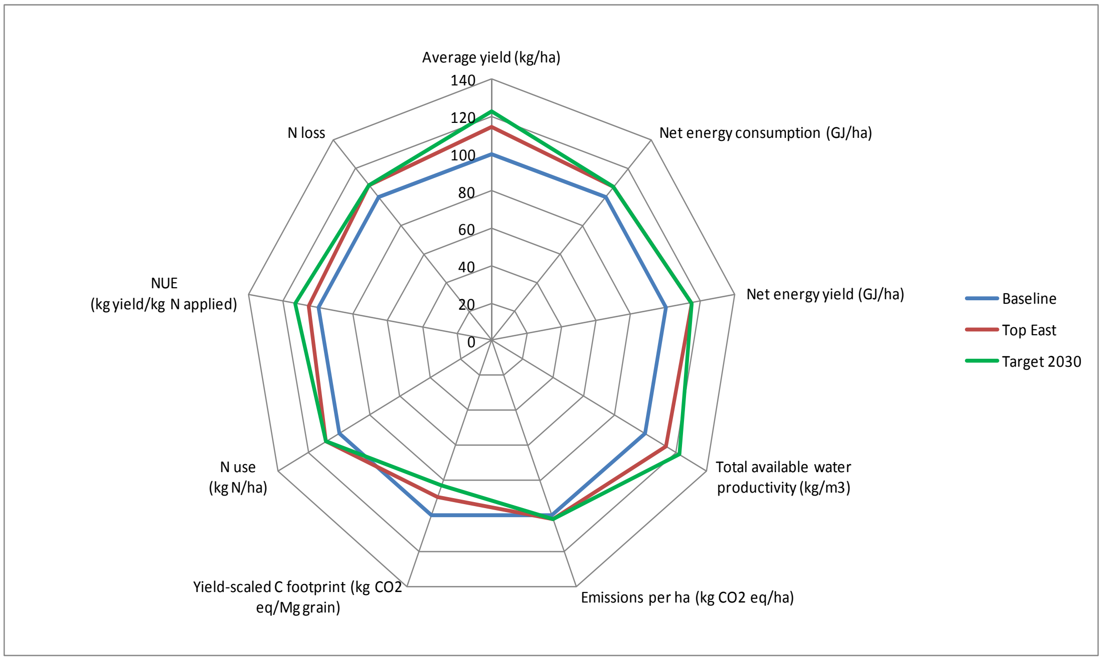
Figure 4. Cumulative distribution of average yields (6 years)

Figure 2 - Evolution of average yield and 90th percentile



Source: SAMAN, Coopar, and Casarone data, BigData workshop, INIA, 2015.

Figure 5. Evolution of average yields, national and best 10% (2001-2014)



Note: Top East refer to best 10% producers from most traditional rice region (East).

Figure 6. 2015 baseline, top East, and 2030 target environmental impact indictors