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Article

Agricultural labour productivity and planetary boundaries: designing just transition pathways for the French dairy sector

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Abstract

Increased farm labour productivity has been at the core of the structural transformation of western economies by allowing the "discharging" (Sauvy 1980) of labour from agriculture to other sectors. Yet, the modernization of the agricultural model also led to numerous environmental impacts in particular increased GHG emissions, pollution, soil depletion and biodiversity loss. The transition to a sustainable food system poses considerable challenge for the evolution of farm practices and the organization of the food chains. How to make this transition a just one - that is, while maintaining jobs and livelihoods for the concerned communities- is a key question that we choose to address by analysing the role of labour inputs and productivity.

This paper discusses the implications of agricultural labour productivity evolutions in a food system that remain within planetary boundaries. Based on a case study of the French dairy sector, it tries to link changes at the farm structure level to changes at the food system level (and ultimately at the national structural transformation level). The development of a modelling tool helps to assess the issue at stakes for a just transition of the dairy sector, which deals with both socio-economic and environmental sustainability.

Keywords: labor productivity, structural transformation, dairy sector, planetary boundaries, just transition

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Introduction

Maintaining food systems within planetary boundaries (Rockström et al. 2009) (Campbell et al. 2017) implies structural changes in farms and industry and an evolution of the product mix, in particular towards a reduction in animal production. Such changes, combined with continued gains in agricultural labour productivity, raise the questions of maintaining agricultural employment and the evolution of agrarian structures (Mazoyer et Roudart 1997) (how many agricultural jobs will there be in the future, of what kind, for what services to society, for what added value...).

This complex question of sustainable transition and jobs is related to the more fundamental debate on the feasibility of decoupling economic growth from resources use and environmental pressure. The distinction between biophysical growth in volume and economic growth in monetary value is, in this regard, fundamental. While the plausibility of fully decoupling economic growth in value from resource consumption (growth in volume) seems low (EEA 2021), alternatives development pathways such as doughnut economics or degrowth offer valuable insights (Jackson 2011) (Raworth 2017). These new paradigms show that incremental efficiency gains within established production and consumption systems would not be enough to tackle the environmental crisis and they call instead for fundamental transformations to a different type of economy and society.

While we do not directly address this debate, we choose to focus on the relationship between growth, productivity, and work through a questioning of the notion of agricultural labour productivity. Increasing labour productivity has been at the heart of agricultural economics for many years, both at the macroeconomic level -through structural change pathways- and at the microeconomic level - notably around the concept of Total factor productivity (TFP).

To embody our reflection, we will rely on a foresight modelling analyse conducted on the French dairy sector. This analysis explores contrasting pathways for agricultural labour productivity evolutions in a context of dairy cow herd reduction to stay within planetary boundaries – and their respective impacts on farm jobs and farm's structure.

The paper is intended to be a programmatic reflection on the challenges of a just transition in the agricultural sector - a just transition defined as a transition to a green economy providing decent jobs and livelihoods for all, organized around a conceptual reflection on agricultural labour productivity applied to the dairy sector. It is organized as follows: A first conceptual part that questions the concept of agricultural labour productivity, its evolutions and a critical assessment of its current use. A second part presents the case study, the model developed to answer these questions and some results that make it possible to identify, in a third part, the key questions that agricultural economists should address to accompany the just transition of the agricultural sector.

1. the concept of agricultural labour productivity, its evolutions, and critical assessments of its current use

Addressing labour productivity in agriculture call for a comprehensive understanding linking both a microeconomic and macroeconomic approach.

a. Labour as a key production factor in the assessment of agricultural productivity growth

On a microeconomic perspective, agricultural labour is a key production factor for the growth of agricultural output, additional to land and capital, as described in the equation (1) below (Mounier 1992)

$$Y = f(L, W, K) + Ef \qquad (1)$$

y: rate of change of agricultural output

f: rate of change of volume of factors of production (L: land, W: labour, K: capital)

Ef: rate of change of production factor efficiency or productivity

Prior to the beginning of the twentieth century, almost all increase in agricultural output occurred because of increase in the volume of one factor of production: land. The area cultivated was the corner stone of the first economic theory of the physiocrats who believed that the wealth of nations derived solely from the value of agricultural land. In a century, the drivers of agricultural output growth radically changed from land production area to production factor efficiency. Ruttan described this movement as a transition from a natural resource based to a science-based system of agricultural production (Ruttan 2002).

Today, the performance of farms can be measured using different ratios: yields which measure productivity in volume per unit area, or labour productivity which measures the production capacity per worker. Similarly, capital productivity measures the production capacity for a greater or lesser level of capital. These different factors, taken individually, refer to partial productivity factor. They are interdependent: an increase in labour productivity may in fact results from a higher use of capital which in turn could contribute to lower capital productivity.

b. The concept of total factor productivity and its limits

To overcome these interdependence effects, economists created the concept of total factor productivity (TFP) which aggregates the overall level of input used to generate a given output quantified in monetary terms. The Solow growth model (Solow 1957) to measure aggregate productivity, lays out the foundations of what is called Total Factor Productivity analysis. Economists reason in terms of growth of this TFP, given that it aggregates a set of inputs and outputs, it is indeed difficult to interpret this indicator as such, directly. Multifactor productivity growth in agriculture could then be defined as the variation in agricultural output that is not accounted for by the variation of the volume of all or several agricultural inputs, namely land, capital, labour, and intermediate inputs. TFP growth can be measured using different methods , either through ratio or through difference-based functions (Abad et Ravelojaona 2020). The most common method being the growth accounting approach, which consists in measuring the difference (ratio) between the growth in total output and the growth in total inputs in monetary terms. On the other hand, the stochastic frontier approach is based on estimation of production function, one being based on the observed production process (inefficient production) and one being theoretically determined by assuming the absence of inefficiencies (frontier production). The distance to the frontier can be approximated to the change in technical efficiency (FAO 2018)

TFP explains most of the growth of agricultural output since 1970s in Europe, shifting from input intensification that use to be the primary driver. Some research works estimate that increasing efficiency input use explain three quarter of output growth in the 1990s and the 2000s (Coomes et al. 2019).

Three main sources of multifactor productivity growth are identified (FAO 2018):

- Technical efficiency: better combination of inputs (efficiency gains)
- Technology: adoption of new and more efficient inputs
- Economies of scale: marginal costs decreasing with increasing outputs.

Thus, the increase in farm performance according to this reasoning would only be a matter of optimisation, and technical innovations. Advance in genetics in the livestock sector is a key example with a constant increase of the food conversion ratio that allow to reduce feed inputs for growing output.

Despite its empirical importance, TFP concept raises number of issues:

Firstly, TFP only considers economic factors of production, in the sense of “marketed” factors, and thus leaves behind essential factors of production such as natural resources. Thus, part of the growth in the multi-factor productivity of farms can be achieved at the expense of these natural resources: this is notably the case of the depletion of agricultural soils, or the disappearance of pollinators, which today call into question the very possibility of agricultural production. This raises important concerns on the sustainability of the agricultural system, defined as the capacity to support long term production. In this regard, the dominant pathway of productivity growth – including massive growth in reactive nitrogen use and land system change- may ultimately have served to undercut the long term sustainability of agriculture (Coomes et al. 2019). In addition to natural resource use, TFP also doesn’t consider pollution such as GHG emissions. Yet the contribution of the modernization of the agricultural sector to anthropogenic climate change is widely documented (Campbell et al. 2017) (Poux et Aubert 2018), and is affecting, in return, the process of agricultural TFP growth. There are already evidences that climate change has slowed global agricultural productivity growth: recent research work indicates that anthropogenic climate change has reduced global agricultural TFP by about 21% since 1961, a slowdown that is equivalent to losing the last 7 years of productivity growth (Ortiz-Bobea et al. 2021)

To overcome this significant environmental bias, researchers are trying to adjust TFP by considering growth contribution of natural capital and by applying growth adjustment for pollution abatement. This efforts led to new indicators such as “environmentally adjust multifactor productivity” that are still being developed (Cárdenas Rodríguez et al. 2018)

More broadly, we consider that TFP could also be problematic beyond the environmental limits already described. TFP is a complex indicator that puts non-compatible factors of production on an equal footing. Indeed, as we have seen, the aggregation of several factors of production certainly has the advantage of compensating for the effects of interdependence between the factors of production, but it also leads to "blurring" the causes for the increase in productivity under the same indicator of growth, defined as the only technical horizon.

Consequently, this indicator prevents us from considering the role of specific production factor, especially labour, in the evolution of the production process, thus contributing to depoliticise the debate. For political economy purpose, we choose to focus on labour productivity for its fundamental explanatory potential of the changes at play in the agricultural system.

c. Agricultural labour productivity at the heart of the structural transformation

On a macroeconomic perspective agricultural labour productivity is at the heart of structural transformation of the economy.

The structural transformation describes the critical period for national economies where agriculture represents a declining share of the economy and labour moves to the cities (Timmer 2009). This is based on theoretical economic model which describes the capacity of the agricultural sector to free labour force and to produce wealth thanks to increasing productivity (Lewis, 1954). On one side, agriculture provides labour and savings in addition to low-cost food to the process of industrialization and urbanization and, in turn, industry provides increasingly cheaper agricultural inputs that improve yields and technologies that enable farmers to cultivated larger free area. This "Lewis Path" ultimately leads to a "world without agriculture" (Timmer 2009) where the share of agriculture in both total labour and value added is 2-3% once productivity and income across the agricultural and non-agricultural sectors have converged (Dorin and al. 2013).

Thus increasing labour productivity in the farming sector is seen as a way for country to develop by "discharging" (Sauvy 1980) the agricultural workforce to other sectors and the same time improve the living conditions in rural area by closing the income gap with urban jobs.

Yet, This path is dependent on a favourable political, socio-economic and environmental framework, which no longer seems to be present today (Bosc et Bélières 2015). Especially, the structural transformation has led to negative externalities linked to farmland intensification: natural resource depletion, biodiversity loss, global GHG emissions, animal and human health problems (Dorin et Landy 2009);

Moreover, as demonstrated in Dorin and al. 2013, the question of structural transformation in agriculture cannot be asked in a uniform manner in every world regions because of two major obstacles: land constraints (i) in countries where access to land remain limited, while the growth of available land per farmer is a key driver of bifurcations in structural transformation paths. And "fine-tuning" (ii) of productivity growth in agricultural and non-agricultural sectors to solve the "discharging" problem from the latter to the first.

The example of India is striking on this manner: with the Green Revolution, the gap in agricultural yield with the developed world has been closed, whereas the gap in agricultural labour productivity has, in fact, greatly widened. Agricultural income has been incapable of keeping pace with the increase in yields, particularly because the development of economies of scale through farm enlargement was not possible in a land constraint context. Moreover, the industrial mode of production that led to this increase in yields now reveals a deepening agrarian crisis, with the massive use of inputs costly both in monetary and environmental terms (Dorin 2021). In fact, such situation could be held as a "Lewis's trap" where farmers are increasingly numerous and poorer compared to other workers, that call for alternative path of development (Dorin 2013)

To summarize, increasing labour productivity has been beneficial for countries that could engage in a structural transformation path, but it is not replicable everywhere and it contributed to the environmental crisis that the agricultural system is now facing.

d. Agricultural labour productivity development pathways within planetary boundaries

The concepts of "planetary boundaries" introduced by Rockström,(Rockström et al. 2009) are intended to represent Earth system processes, which, if crossed, could generate unacceptable environmental change potentially endangering human existence. Together they define what he calls a "safe operating space for humanity".

The agricultural system is a major driver of the transgression of these boundaries with two being already at high risk: biosphere integrity and biogeochemical flows, and three at increasing risk: land system change and freshwater use and climate change (Campbell et al. 2017)

Bringing the EU food system back within planetary boundaries would imply – amongst other things – a strong protein transition whereby the amount of animal proteins production and consumption strongly decreases while at the same time the environmental impacts of livestock productions systems are reduced (Poux et Aubert 2018).

A transition to less and better animal production implies fundamental changes at the farm level but also more broadly at the way the food and system is organized. The evolution of labour productivity in livestock system would be a key component of the transition pathway. Continuous rising labour productivity in a sector that would have to face a decrease in global output would generate a massive loss of jobs. The equation (2) below shows the simple relation between the level of production in volume (Y), the total labour input (W) and labour productivity (Wp) expressed in volume produced per worker.

$$W = \frac{Y}{W_p} \qquad (2)$$

Indeed, if an economic sector doesn't grow fast enough to offset this increase in labour productivity, then the number of jobs available will decrease. This phenomenon called the productivity trap (Jackson et Victor 2011) explains why any attempt to stabilise or reduce economic output as a means of reducing resource throughput or environmental impact is viewed as a direct threat to jobs and people livelihoods.

Labour input could be further broken down into total number of working people (F) and working hours (h)

$$W = F \times h \qquad (3)$$

In this condition equation (2) become:

$$W = \frac{Y}{W_p \times h} \qquad (4)$$

In a context of decreasing global output in a sector (Y), two solutions remain to maintain full employment (W) : either (i) to reduce working hours (h) or (ii) to slow down physical labour productivity (Wp), ie decrease the volume produced per worker. The first option would mean to reduce working time to allow a better distribution of the available work, what Hayden call "sharing the work to save the planet" (Hayden 1999).

The other way to escape the productivity trap would be to question the continued pursuit of physical labour productivity growth in livestock farms. This would not only maintain jobs in rural communities; but it could also contribute to generate benefits for biodiversity and health. Regarding biodiversity, serious evidence points to the fact that small farms in the EU are, on average, more labour intensive while performing better in terms of biodiversity preservations(Hass et al. 2018) (Benton, Vickery, et Wilson 2003), and that more generally greater landscape heterogeneity and complexity is key to biodiversity conservation and ecosystem services provision (Dainese et al. 2019). Recognition and payment for the ecosystem services provided by farmers would be crucial to ensure a just remuneration while labour productivity is decreasing. This would imply a shift from volume intensive to value intensive production, by selling less products and more what could be called green services (Jackson et Victor 2011). To study such changes, it seems crucial to develop an analytical framework that takes into account both the national scale and the farming-system scale, as well as agronomic balances and socioeconomic structural change processes at both scales (Schwoob et al. 2019).

In the next section we propose a modelling tool that try to assess the impacts of food system sustainable transformations on farm jobs in the French dairy sector, linking farming system scale with national-scale transformation.

2. Assessing the impacts of food system transformations on farm jobs in the French dairy sector

Assessing the socio economic impacts of environmentally sustainable transitions of the food systems is a key challenge which is for now facing two main limits: first of all widely used socio-economic models which capture the impacts of transitions can only consider marginal changes to the food system (Dorin et Joly 2020). This means that they cannot deal with scenarios involving biophysical breakthroughs, although such scenarios are necessary if we are to bring back the food system within planetary boundaries(Springmann et al. 2018) (Clark et al. 2020). Conversely, models specialised in exploring biophysical transformations are unable to capture their socio-economic impacts (Dorin et Joly 2020) (Schader et al. 2015). While different attempts have been made to develop ecological macroeconomics frameworks (Jackson 2011) (Jackson et Victor 2020), they have been mainly applied to the energy sector and the agri-food sector has so far not been analysed through such a lens.

Against this backdrop, we developed a conceptual model of food systems dynamics called MOdel of FOod systems Transitions (MOFOT) (P.-M. Aubert et al. 2021). This model explores the socio-economic impacts of ambitious food system transformation scenarios and helps identifying the political and societal levers for a just transition. MOFOT explores the potential transformation at farm, industry and consumer levels. In this paper, we focus on the modelling tool use at the farm level : SP-Calc.

a. A biophysical framework compatible with planetary boundaries

The starting point of the analysis is the definition of a biophysical framework compatible with planetary boundaries. Our analysis relies on the indicative decarbonisation pathway for the agricultural sector laid down by the official French National Low-Carbon Strategy which aims to halve greenhouse gas (GHG) emissions from the agricultural sector by 2050 (MTES 2020). These projections are based on a physical & agronomic representation of French agriculture, on a 5-year time scale, in terms of surface area, livestock, yields and associated production, and cover all sectors and sub-sectors.

Among all sectors covered by the National Low-Carbon Strategy, we focused on the analysis of the dairy sector for its importance for the French economy in terms of land use, employment and total value added generated. Dairy farms account for 32% of the utilised agricultural area (UAA), 26% of the Annual working unit and 28% of the standard output according to the latest farm structure survey (Agreste 2016). Given the high level of uncertainty when assessing economic changes, we also chose to work with a 2030-time horizon rather than 2050. Besides, this time horizon is more adapted to engage stakeholders in the design of scenarios, as was done in this study (see below the storyline development section).

In the case of the dairy sector, these projections envision a series of changes by 2030, playing with the four main levers of decarbonation of the AFOLU sector (Svensson et al. 2021): increasing efficiency to decrease GHG emissions / kg of milk produced using different approaches ; maintain / increase carbon sinks through the preservation of extensive grasslands and the development of temporary grasslands (Pellerin et al. 2017); developing biomass-based renewable energy to substitute fossil fuel through anaerobic digestion of dairy manure; and eventually decreasing the overall herd size to reduce further emissions. Figure 1 shows the projected evolution of the dairy herd against historical trends and the evolution of the cattle herd.

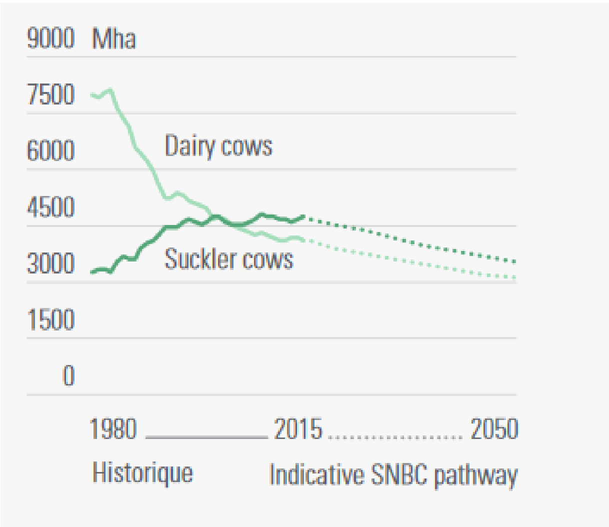

Figure 1. *Evolution of the dairy and cattle herd as envisioned by SNBC-A with regard to the 1980-2015 dynamics (source: authors, based on (MTES 2020))*

Taken together, those changes imply massive evolutions for dairy farms and poses serious challenges for the number of farm jobs that could be maintained. In order to provide reliable and transparent data regarding the potential consequences of the transition, we developed a modelling tool, SP_calc, that is be described in the next section.

b. A simulation tool to assess the impacts of food system transformations at the farm level: SP_calc

SP_Calc apprehends the impacts on employment of a given agronomic scenario by focusing on the physical labour intensity of the production. The general reasoning can be approached through Equation (5)

$$L = LI \times Y \quad (5)$$

where L is the total labour force employed, LI the labour intensity, and Y an indicator of the total production relevant for the sector considered. Y depends on the agronomic scenario taken as a starting point, while LI depends on production methods.

The methodology used to analyse the dairy sector entails a three steps approach. First, characterise the current situation and develop storylines. Then, determine the value of LI and Y on plausible and relevant assumptions regarding potential transformations of economic units. Finally, assess the impacts on employment. It is important to mention that we restrain the analysis to the French economic system. This means that the impact of the scenarios in terms of employment are only estimated for France and do not consider the possible transformations that they may generate in other countries as a consequence of French food system transformations.

To develop storylines and infer from these coherent assumptions regarding the evolution of the farm systems, the overall approach proposed here relies on a series of stakeholders' workshops held between September 2018 and June 2020. During these workshops potential evolution scenarios at farming system, industry, and consumer levels were developed and tested. Each workshop gathered between 15 and 25 actors coming from diverse background: farmer union representatives, technical institutes, industry representatives, retailers, NGOs (including consumer organizations), administrative bodies, and scientists. The first workshop (25 September 2018) aimed at presenting the overall study and approach; the second workshop (22 February 2019) aimed at validating the baseline; workshops 3 (17 September 2019) and 4 (9 April 2020) were used to test and adjust different set of assumptions at both farms, processing, and consumption levels. Finally, workshops 5 (12 June 2020) and 6 (17 July 2020) served to discuss the results, adjust the set of assumptions, and draw policy implications from the results.

At the farm level, the characterization of the baseline relies on FADN data, a review of existing typologies as presented for the dairy and cattle sectors (Gac, A., et al. 2016) and expert interviews to establish a national-scale typology of existing farms. This typology is based on both agronomic and socio-economic variables, following the logic of farming system analysis (Cochet 2012). Each farm type is characterised by its endowment in production factors (Usable Agricultural Area (UAA), fixed assets, labour force—both family and non-family one) as well as the main characteristics of technical itineraries (in particular feeding strategies for the dairy herd, crop rotation and share of permanent grassland in the UAA) (Figure 2). Each farms in the FADN sample has an extrapolation coefficient that enable to extrapolate the results observed in the sample to the global national farm population[1]. Thus we were able to offer a representation of national dairy farms with our farming system types and their respective weight in the global population (see Table 1 in Appendix for the weight of each farming system and their main quantitative characteristics).

The second step consists in exploring potential evolutions of existing farming systems by 2030 in the framework of the SNBC. The underlying hypothesis is that these evolutions are shaped by two key aspects: the situation of the farm as of today; and the farmer's strategy. Following Cerfrance, 2019, two indicators are considered to apprehend farmers' strategies: the level of concentration (farm size) and the specialisation. Based on these two indicators, an evolution matrix combines four possible development strategies (Figure 3). A third additional indicator is considered to delineate the key characteristics of 2030 farming systems: the need for certain farms to adopt the practices identified

[1] FADN statistical database focuses on large and medium-sized farms with a standard output (SO) of over €25,000. For France, the sample includes 7,284 farms, extrapolated to 296,800. Although this only represents about 70% of the total number of farms (450,000 in 2013), large and medium-sized farms are statistically significant. Indeed, they account for 95% of production potential and 90% of land area.

by the SNBC to reduce emissions. Through this approach, the labour intensity of the production can be approached for each type of farming system, expressed in terms of number of jobs per thousand litres of milk produced. The quantitative characteristics of the resulting farms are estimated based on innovative farms already present in FADN data and adjusted based on experts interviews and stakeholder workshops (see Table 2 in appendix).

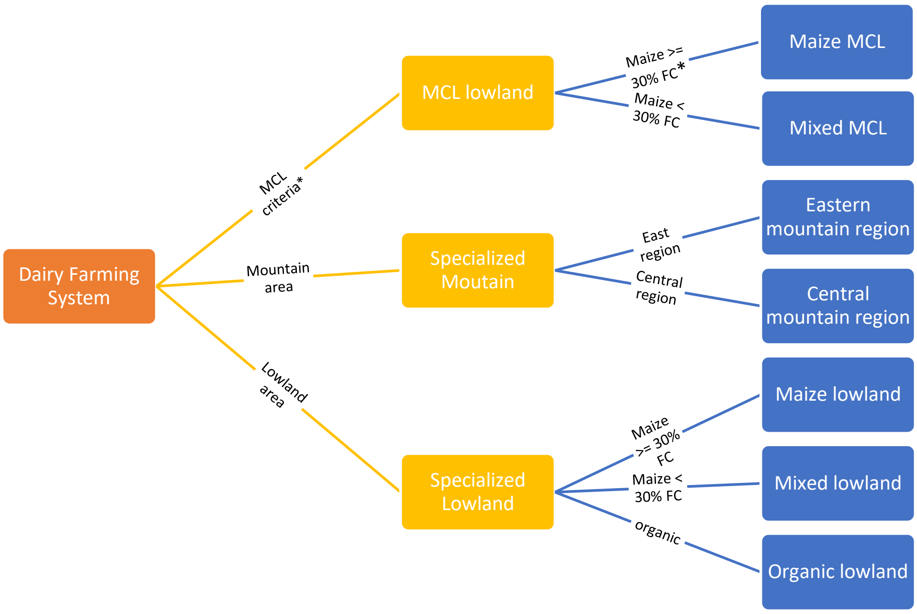

Figure 2: 2015 Dairy farming system typology and sorting criteria. MCL: Mixed crop-livestock systems, FC: Forage crops ("Surface Fourragère Pincipale" in French), MCL criteria: dairy farming systems with less than two thirds of the UAA in fodder or with more than 40ha of crops (Perrot 2017)

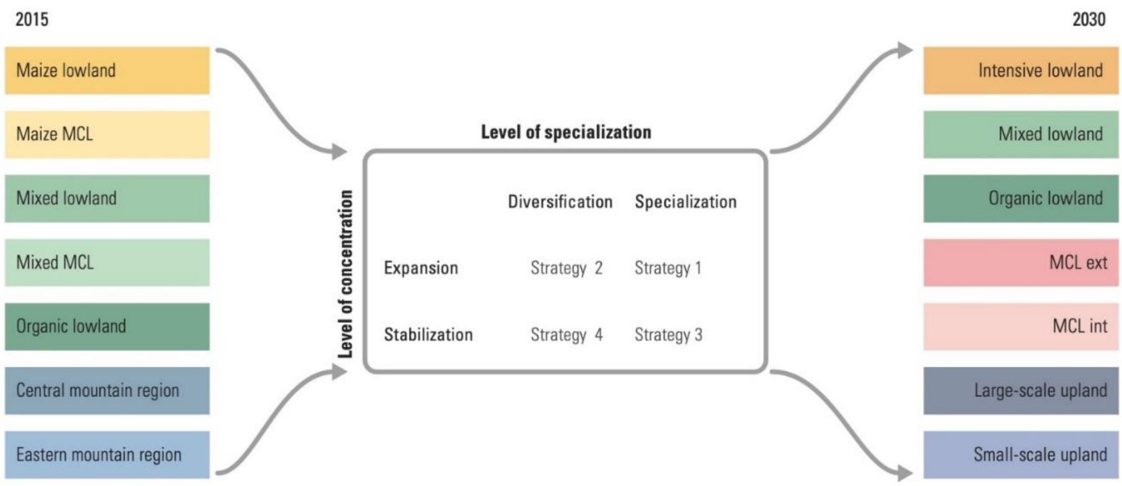

***Figure 3.** Analysing farming systems' potential evolution to 2030 (source: authors). MCL: Mixed crop-livestock systems; Ext: extensive; Int: intensive*

The third step of the analysis aims to construct populations of 2030 farming systems that are coherent with (i) the biophysical targets set by the SNBC, (ii) a set of more general assumptions derived from the broader socio-political storylines (e.g., average size, specialisation level, demographic framework, regionalisation criteria) and (iii) the plausibility of transitioning from one farm type to another one. The precise number of each type of farming system in the 2030 population is calculated by means of a Microsoft Excel solver that makes it possible to identify the solutions that respects all proposed assumptions. Once the 2030 farming system population is determined, the resulting number of jobs can be calculated from the labour intensity of each farming system:

$$L_{2030} = \sum(LIFS_{2030\,i} \times FS_{2030\,i}) \qquad (6)$$

where L: total number of jobs, in annual work unit (AWU). FS_{2030} i: number of type i 2030 farming systems. $LIFS_{2030}$ i: Labour intensity of the type i 2030 farming system.

c. The results

i. Contrasted scenarios

Based on contrasted storylines (see (P. M. Aubert et al. 2021)) we explored two scenarios that are both compatible with the SNBC biophysical framework but that have different hypothesis regarding farm evolutions.

- "Socio-territorial recompositions": this scenario corresponds to the development of farmers' strategies seeking to maximize the economic productivity of labour (thus moving away from considering productivity in terms of volume) in particular through product differentiation and inputs saving for example with grassland based system (Devienne et al. 2016). Beyond the adoption of new techniques, changes in farming systems are of a systemic nature and the entire rationale of production evolves towards maximizing the use of ecological processes. Average farm size continues to increase but at a much slower pace than during the 2000-2020 period.
- "Dual France": In this scenario the trends towards the concentration and intensification of farming systems continues to intensify (Clay, Garnett, et Lorimer 2020), while environmental imperatives are integrated into farm growth strategies. This leads to farms becoming larger and larger, more and more specialized, with a decreasing trend in the labour intensity of farms.

Moreover, we developed two sets of alternative pathways that push the rationale of each of the two scenarios to the extreme to test the sensitivity of the model:

- "Employment +" takes seriously the demands of civil society actors (see for example (Girod, et al 2020) in favour of a significant increase in the rate of new farm establishments and a deceleration in farm concentration
- "Danish Model" envisages a generalization of the average Danish dairy farming system to the whole of the French dairy herd. On average, dairy farms in Denmark have 173 dairy cows, almost three time bigger than the average French farms with 60 dairy cows.

For more detail on the quantitative profile of each of the pathways, see the Table 4 in appendix.

ii. Impacts on employment

Each of the four pathways has contrasting outcome in terms of agricultural jobs. As one would expect, the evolution of jobs is linked to the evolution of average labour productivity (Figure 4).

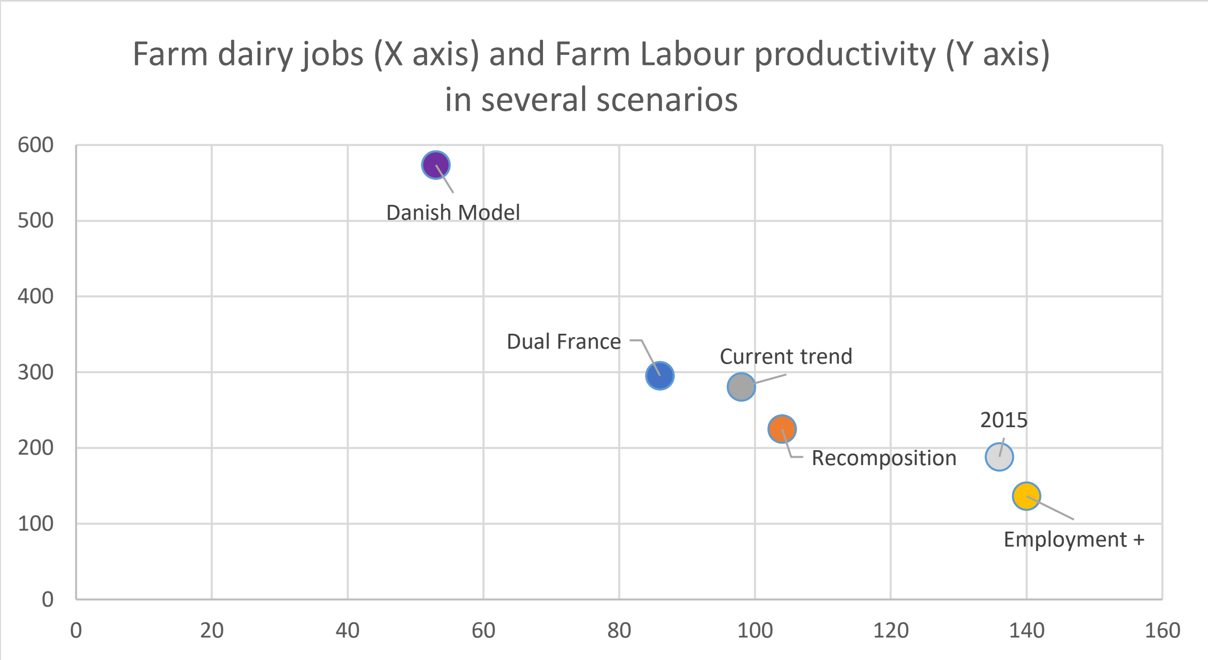

Figure 4: Farm dairy jobs (1000 AWU) and mean agricultural labour productivity (t milk/AWU) in the French dairy sectors in several scenarios

The first result is that, despite the reduction in total production, a low-carbon and agro-ecological transition could maintain more jobs than a continuation of the current trend. This is the case in the *Socio-territorial recompositions* scenario where 8,000 farms and 5,200 jobs could be maintained in the dairy sector compared to the current trend. This is possible due to the evolution of the global context, that enable a slowdown in labour productivity gains with the development of new strategies for diversification and of more upmarket products.

For the low carbon transition to maintain current level of jobs in dairy farm, in the *Employment+* scenario, the current labour productivity level would have to decrease. This is based on the massive development of very small farms (with 30 dairy cows or fewer) – which would represent 40% of farms and 27% of the herd by 2030. Such a situation would also lead to a decrease in production (25% less compared to 2015), as the average productivity per dairy cow of these small systems has a much lower potential for growth than large, highly automated systems. Finally, it would require 24% of the milk produced to be processed directly on the farm to ensure sufficient value added, and to remunerate a stable workforce despite the drop in volumes – compared to less than 2% today.

On the other hand, in a context where price competitiveness is strengthened and where political support focuses on the mitigation of climate change, the increase in labour productivity would remain the main factor of competitiveness. Most farmers' strategies would lead to a highly significant reduction in the number of jobs through a reinforcement of capital/labour substitution. It is estimated that the *Dual France* scenario would lead to the loss of 7,000 farms and 13,000 jobs compared to current trends.

In a more extreme manner, the *"Danish Model"* scenario is based on an exacerbated rationale of concentration/intensification/specialization of dairy farms. It would lead to an extremely high loss of farms (71% fewer than in 2015, 35% fewer than the Dual France scenario) and jobs (similar orders of magnitude) at the agricultural level.

3. Discussion

a. Linking farming system scale with national-scale transformation

Our modelling approach tends to build an analytical framework that takes into account both the national scale and the farming-system scale, as well as agronomic balances and socioeconomic structural change processes at both scales (Schwoob et al. 2019). By looking at the current farming system and their potential evolution given the situation of the farm as of today and the farmer's strategy, we outline that it is crucial to deal with the changes that farm structures are already experiencing (Bosc et Bélières 2015).

Then, analysing the national farming system distribution within a given pathway allows us to link changes in farming systems with changes at the national scale related to the structural transformation of the economy.

Our simulation also allows us to reason in reverse by asking: what farm structures would be compatible with given visions of global transformation of the green economy? In the Employment+ sensitivity test we outline that to maintain farm jobs in a context of decreasing output, new farming systems with lower production but important valorisation would have to emerge. It poses questions not only in terms of production systems but also more broadly in terms of activity systems with the development of other activities on the farm (farmer cheesemaker for example).

More broadly, our methodological framework allows to deal with the coexistence of several individual strategies within each pathways of change. Thus, each of the pathways represent a combination of several farming systems with different evolution strategies.

b. Questioning the role of labour productivity

By developing an innovative methodological framework, we show that the evolution of agricultural labour productivity is at the core of the sustainable transition of agriculture.

In a context of a reduction of the production level to stay within planetary boundaries, we have seen that continued gains in labour productivity would lead to a massive reduction in farms jobs. Nevertheless alternative pathways with a slowdown of labour productivity do exist. The challenge is then to differentiate between the most painful tasks for which labour productivity gains should continue to be improved and the tasks for which high labour intensities must be envisaged to preserve the environment.

Recognition of the central role of farmers in ecosystem management requires the development of more labour-intensive activities. The emergence of what could be called environmental services is thus at the heart of a new vision of agricultural modernisation. In this context, agriculture could represent a source of jobs in the transition, provided that these environmental services are recognised and valued. Beyond a vision of "world without agriculture", such a trajectory constitutes a paradigm shift towards an alternative "farmer-inclusive" path with maintaining of farm jobs and a comparable income with non-agricultural workers (Dorin, Hourcade, et Benoit-Cattin 2013).

The remuneration of the new green services would then need to offset the drop in production volume caused by the reduced labour productivity (Jackson et Victor 2011). It entails a shift from increasing productivity in volume to increasing productivity in value. The challenge is to explore the conditions for increasing the value of production in a context of reduced production volume, in other words how to produce less and better, with better remuneration.

In addition to remuneration for environmental services, such a transition could also be based on the capacity of farmers to add value to the raw product and to capture it through conservation, processing, and marketing in the territories (Bosc and Bélières 2015). At the same time, the question of a better distribution of value along the food chain is also central. Indeed, studies have shown how productivity gains made by farmers could be captured upstream and downstream (Veysset et al. 2019).

The economic assessment of alternative pathways with low agricultural labour productivity goes far beyond the scope of this paper and would imply further development.

Two key questions are identified. Firstly, the evolution of production cost at the farm level link to the need of new investments for the transition and raising labour cost in a context of low productivity gain. This in turn raises the crucial question of consumption and competitive dynamics: will national and international consumers continue to buy French milk and dairy products if they have the possibility to buy cheaper ones produced by Danish or German producers? This would depend on (i) how domestic demand is accompanied; and (ii) how the Common market is organized in the future.

More broadly the impact of such transformation on the rest of the value chain would also need to be carefully analysed. For example, the development of on farm processing could lead to reduce the volume processed by the industry and affected related jobs. In the study (see (P. M. Aubert et al. 2021)) on the just transition, we also take into accounts processing industry dynamics and evolution.

Finally, although the dairy sector plays an important role in France in terms of utilized agricultural area, employment and value generated, there is a need for a comprehensive analysis across all the agricultural sector to analyse the trade-off between one another. The reduction of farm jobs in animal farms could for example be offset by the development of vegetal production in a context of protein transition. Analysing cross-sectoral evolutions in the context of the protein transition is indeed a major challenge that call for further developments.

Appendix

	Maize lowland	Mixed lowland	Organic lowland	Maize MCL	Mixed MCL	Mountain central region	Mountain Eastern region
UAA (ha)	92	114	96	148	195	82	100
Standard deviation (+ or - %)	*56%*	*56%*	*67%*	*57%*	*47%*	*67%*	*63%*
AWU	2,1	1,9	2,1	2,4	2,5	1,7	1,9
Standard deviation (+ or - %)	*48%*	*49%*	*51%*	*46%*	*42%*	*50%*	*52%*
Dairy cow (heads)	69	56	51	68	61	45	51
Standard deviation (+ or - %)	*48%*	*50%*	*55%*	*46%*	*47%*	*58%*	*55%*
Productivity (l/DC)	7 336	6 567	5 322	7 766	7 170	6 088	6 399
Milk production (t)	503	367	273	525	438	274	326
Share in dairy farms numbers 2015	28%	21%	6%	16%	6%	12%	10%
Share in national milk production 2015	34%	19%	4%	20%	7%	8%	8%

Table 1 : 2015 dairy farming systems main characteristics and weight in the global dairy farm population (Source: FADN)

	Intensive lowland	Mixte lowland	Organic lowland	Large-scale upland	Small scale upland	MCL intensive	MCL extensive	Danish average farm 2016	On farm processin dairy system
UAA (ha)	400	150	75	180	100	250	150	157	-
Permanent grassland (% of UAA)	35%	50%	85%	75%	100%	25%	30%	-	-
Workforce (AWU)	6	2,5	2	2,5	2	3	2	2,9	2
Share of salaried workforce	21%	14%	6%	13%	4%	23%	17%	-	-
Dairy cow (head)	300	80	50	80	50	100	60	173	30
Yield (l/DC)	9 500	7500	6000	7000	6000	8500	6500	9500	6500

Table 2: 2030 dairy farming system main characteristics (Source : authors)

	Intensive lowland	Mixte lowland	Organic lowland	Large-scale upland	Small scale upland	MCL intensive	MCL extensive	Danish average farm 2016	On farm processing dairy system
2030 Dual France	4 000	10 680	252	7 950	-	3 520	2 133	-	-
2030 Socio-territorial recomposition	500	11 625	7 200	1 525	7 161	9 515	5 474	-	-
2030 Employment +	200	2 000	20 000	-	10 000	1 000	9 000	-	28 000
2030 Danish model	-	-	-	-	-	-	-	18 497	-

Table 3 :Number of each 2030 farming systems in the respective pathways (Source: authors from SP_Calc)

	Average number of DC / farm	Average productivity / DC (l/DC)	Milk production (bn l)	Number of farms	Number of agricultural jobs (AWU)	Average labour productivity (Tmilk/AWU)
2015	60	7 014	25,6	66 000	136 000	188,24
Current trend 2030	100	8 594	27,5	35 000	98 000	280,61
Recompositions 2030	75	7 313	23,4	43 000	104 000	225,00
Employment + 2030	45	5 969	19,1	70 000	140 000	136,43
Dual France 2030	115	7 938	25,4	28 500	86 000	295,35
Danish Model	173	9 500	30,4	18 500	53 000	573,58

Table 4 : French dairy sector trends and modelised evolution in four contrasting pathways (Source: FADN and authors from SP_Calc for the scenarios)

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