The impact of technology evolution and the access to fossil-fuels and electricity to land and labour productivity in Europe since 1970

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ABSTRACT

Currently, global studies like the project by Paul Steenwyk have made significant strides in understanding the impact of technology evolution and the access to fossil-fuels and electricity to land and labour productivity. However, due to cultural and regional differences, as well as disparities in technological progress, these global datasets often fall short of providing an accurate representation for specific territories. Recognizing this gap in the research, this project aims to provide a more localized and detailed analysis, with a particular emphasis on Europe. This study uses data from 1970 and beyond, a time when we have a good and dependable database. By using this database and adding information from the Food and Agriculture Organization (FAO), the project provides a detailed look at Europe.

However, this thesis aims to do more than just collect and analyze data across Europe. This research also offers a significant solution to the urgent problems of our time. To this end, the project suggests a 100% renewable energy solution, which could help lessen the environmental harm caused by using fossil fuels in farming. The project imagines a future where farming thrives on renewable energy, adding to global efforts to combat climate change.

1. INTRODUCTION

The initiation of this study stemmed from a recognized need for an energy examination tailored to European farming. The intention is to continue the work done by Paul Steenwyk [1], titled "A worldwide time series of energy for human and animal muscle work for all industries and end-use"

In this project, the energy output of both animal and human work will be calculated, including both useful and final energy. The study will also utilize data from the FAO to determine the useful energy of electricity used in agriculture. Through the efficiencies of electric motors, the final electrical energy will be obtained. The quantity of fuels utilized in agriculture will also be calculated and converted into final energy through tractor efficiencies.

To calculate the work done by humans and animals, we used the same data Paul did. This allowed us to tell the difference between East and West Europe. But for the land that could be farmed in Europe, we used data from the FAO, which had this information for each country. On the other hand, this project, unlike Paul's, only focuses on the primary energy of mechanical work because it wasn't specificity data from just Europe. It does not consider the secondary, tertiary, or transport energy. These simplifications are explained in the methodology developed in the thesis. To be able to compare the results worldwide, calculations will be done again with the mentioned simplifications.

The proposed solution consists of a chicken farm for egg production and a vineyard. Real-case data from a vineyard in Alentejo will be incorporated into the study, while information related to the chicken farm will be derived from the literature - specifically, estimates of machine consumption within poultry farming. This data will enable the determination of a demand profile for the entire farm and a solar radiation profile for the Alentejo region. This in turn will facilitate the design of the electrical circuit for the farm, providing an understanding of the energy flow for battery charging and discharging, and satisfying the farm's eco-friendly energy demand.

2. OBJECTIVES

- Complete a detailed study on energy use in agriculture in Europe, expanding on Paul’s research that couldn't be directly applied to specific regions.
- Use existing data sets to calculate both human and animal labour in terms of energy.
- Present simplified calculations of energy use to allow for global comparisons.
- Discuss and analyze the findings in search of trends or patterns and compare Europe to the rest of the world to understand the impact of technology in agriculture.
- Understand the specific needs of the agricultural sector to provide a more energy-efficient solution without compromising productivity.
- Design and simulate a self-sustaining farm powered by renewable energy, offering a more sustainable solution to the current farming model.

3. METHODOLOGY

In this chapter, the method that was primarily used by Paul Steenwyk [1] in his project will be explained, but with modifications and simplifications made to suit the needs of this study. The origin of this methodology will be detailed, as well as the authors Paul used as references. This should provide a better understanding of the method.

Calculations for muscle work only incorporated the agricultural working population and accounted for all food/feed consumption and waste in the final energy computation. The WPFU muscle work database was employed to estimate final energy and physical work inputs to farms, but it did not quantify the Primary-Final-Useful (PFU) energy consumption on farms. It was assumed that all animals assigned for "mechanical work" were used on farms and animal energy data from the WPFU database for "mechanical work" was utilized. The farm-specific data was extracted and disseminated at the global level in the Supplementary Material spreadsheets. The WPFU database data for humans calculated the PFU energy consumption for primary industry workers, encompassing those in agriculture and forestry.

Energy consumption also comprises all food and feed intake, including wastage, for work purposes. This information from the WPFU database was used to calculate the final energy and physical work inputs for human labour in agriculture. Our methodology was predicated on the power output and working hours for each category of human worker, as proposed by prior research. To maintain consistency, we define final energy for both humans and animals as the total food/feed energy intake for all activities, including work and fundamental metabolic needs, plus any food/feed that is wasted or spoiled. This definition assumes that all food/feed bought from a supermarket carries the energy required to fuel both work and metabolic functions.

Farm-specific data from the WPFU muscle work database was used to estimate the final energy and physical work inputs to farms. This data contains the energy consumption for animals performing "mechanical" work and primary industry workers but does not encompass the Primary-Final-Useful (PFU) energy consumption on farms [5]. We assumed that the animals employed for "mechanical work" on farms are the same animals that plow and harvest crops. The data for farm animal energy is sourced directly from the WPFU database, specifically the section on animal energy for "mechanical work." This farm-specific data is shared at the global level in the online resource spreadsheets.

3.1 Muscle Work

The study juxtaposes the energy output of agriculture and forestry (AF) workers, draft animals employed in agriculture, and tractors. By positing that AF workers possess similar work characteristics to those in the primary industry, the proportion of final and useful energy utilized for physical work on farms can be calculated based on the percentage of primary industry workers in Europe operating in AF. To ascertain the number of AF workers (WorkersAF), non-AF workers are deducted from the primary industry workers to determine the total AF workers [1].

$$MW_{animal,e,t,eu} =_{DA_{a,r,t}P_{a,r,t}T_{a,r,t}EU\%_{a,r,t}} \qquad 3.1$$

$$MW_{human,r,t} =_{\sum_{i=1=2} Workers_{r,i,t} \;\; P_{i,r,t}} T_{r,i,t} \qquad 3.2$$

The consumption of final energy for working draft animals is considered as the energy expended by "machines." This energy is quantified as the complete feed consumed by these animals, encompassing waste and feed that cannot be digested. The researchers derive regional final energy data for varying types of animals and regions across different time periods [1].

$$E_f = \frac{Workers_{r,i=AF,t}}{Workers_{r,i=agriculture}} E_{f,i=agriculture} \qquad 3.3$$

3.2 Final Energy Method

The introduction to the section on final energy in this paper focuses on the concept of energy conversion efficiency, specifically from the final-to-useful energy stage. The final-to-useful energy stage refers to the conversion process where the final energy (energy ready for use, such as the energy in fuel) is turned into useful energy (energy used to perform tasks).

$$\eta_F - U_x = \frac{E_{ux}}{Efx} \qquad 3.4$$

The energy conversion efficiency of a human, an animal, or a machine, denoted as (ηF-U,x) is defined as the ratio of the useful energy produced to the final energy consumed. In other words, it measures how effectively a human, animal, or machine can convert the energy it consumes into useful work.[1]

$$\eta_F - U_x = \frac{\sum x\, E_{ux}}{\sum x\, Efx} \qquad 3.5$$

When considering the entire agricultural industry, the overall energy conversion efficiency includes all humans, animals, and machines engaged in agricultural activities. This total efficiency is calculated as the ratio of the sum of all useful energy outputs from all the prime movers (workers or machines performing work) to the sum of all final energy inputs for the same movers. In this way, the paper presents an integrated perspective on energy efficiency in agriculture, accounting for both biological (humans and animals) and mechanical (machines) actors in the process.[1]

3.2.1 Final Energy Animal Work

Now, the calculation for final energy pertaining to animal muscle work is to be undertaken. The computation of muscle work for each region relies on the number of draught animals (DAa,r,t), the average power output per animal (Pa,r,t), and the total hours they worked within a specific year (Ta,r,t). The tasks carried out by animals are categorized into two end-uses: mechanical (agricultural) and transport work. The percentage of the total draft animals allocated to each end-use (EU) category is depicted by EU%a,r,t. The subsequent equation is deployed to calculate the muscle work on a regional basis [1]:

$$FUDA\%_{a,r,t} = \frac{\sum countries\ DA_{estimate,country,a,rt}}{\sum countries\ Pop_{country,a,rt}} \qquad 3.6$$

Total feed consumption for the working animals (DAa,r,t) is estimated based on the region-specific fodder requirements, using the formula:

$$FU_{animal,a,r,t} = (DA_{,a,r,t}(FU_{W,D,a,r,t}, WDPY_{a,r,t} + FU_{NWD,a,r,t}, (365 - WDPY_{,a,r,t}))) \; 3.7$$

In this formula, WDPY stands for the total number of working days per year. For animals, it is assumed that the WDPY remains constant for a given region.

The final energy related to animal muscle work is equivalent to the amount of feed a farmer would need to purchase from a vendor to fulfil all the consumption requirements of his animals. Therefore, the final energy incorporates the waste that happens after procuring the feed from a vendor, as shown in the following formula [1]:

$$E_{f,animal,r,t} = \frac{FU_{animal,a,r,t}}{1 - TroughWaste} \qquad 3.8$$

3.2.2 Final Energy Human Work

In order to determine the final energy for human work, the first step involves calculating the food consumption by individuals engaged in muscle work occupations (FUr,t). This is computed using the equation [1]:

$$FU_{r,t} = \sum_{i=1,2} Workers_{r,i,t}(FU_{rW,D,r,i,t}, FU_{rW,D,r,i,t}, FU_{rNWD,r,i,t}, (365 - FUWDPY_{,r,i,t})) \qquad 3.9$$

In this equation, 'Workers' signifies the quantity of workers involved. The terms 'FUwd' and 'FUnwd' represent the food energy necessary to sustain a worker on working days and non-working days, respectively.

The calculation of FU values for both working days (WD) and non-working days (NWD) is carried out using the equation [1]:

$$FU_{r,i,t} = \left(Multiplier_{i,t}\left[\frac{kcal}{kg - day}\right]Weight_{r,t} + Constant\left[\frac{kcal}{day}\right]\right) \quad 3.10$$

This equation illustrates the breakdown of caloric intake by males and females operating at different activity levels, which correlate to different industries.

Within this equation, 'PAL' stands for Physical Activity Level and is signified by a number ranging between 1 and 2.1. This PAL multiplier provides a quantification of the increase in food intake required by highly active workers compared to their entirely sedentary counterparts.

The final energy required for human labour is computed using the equation [1]:

$$E_{f,human,r,t} = \frac{FU_{r,,t}}{1 - PlateWaste_{r,t}} \qquad 3.11$$

In this equation, 'FUr,t' represents the food consumed by human workers. The term 'PlateWaster(r,t)' denotes the proportion of food that is wasted by humans after they have procured it.

Thus, the equation considers both the energy intake through food consumption by the workers and the energy wasted in the form of food waste to arrive at the final energy used for human labour.

3.2.3 Final Energy Electricity

The final energy in this study was calculated considering the efficiency of the most commonly used agricultural devices over the years, as well as the average yield in energy production. This process is visualized in a graphic that captures the data for these aspects.

Firstly, the efficiencies of the various agricultural devices were assessed. This included equipment like tractors, irrigation systems, and others, depending on their prevalence in the farming practices of the time period being studied [15]. The efficiency of each device was represented as a percentage, indicating how much of the input energy was successfully transformed into useful output energy [1].

3.2.4 Final Energy Fuels

In the process of calculating energy from fuels, the authors acknowledged the vast variety of machinery utilized in agriculture, with a range of efficiencies and fuel requirements. Attempting to track the efficiencies of all these various machines over time would have been an immensely complex task.

To address this challenge, the authors opted to use the efficiencies of tractors as a representative or proxy for all fossil fuel-powered machines. This decision is backed by the understanding that most machines employed in on-farm work are powered by diesel or gasoline engines, similar to tractors [1]. Therefore, the energy characteristics and efficiencies of tractors provide a reasonable approximation for the overall energy use and efficiency of agricultural machinery.

4. RESULTS AND DISCUSSION

4.1 Animal muscle work

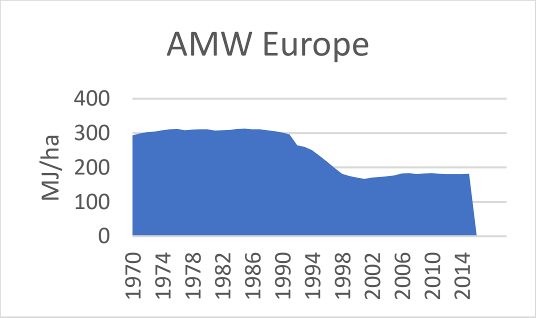

Figure 1 Animal muscle work in Europe [1] [6]

This figure represents animal muscle work in agriculture specifically in Europe. It illustrates a downward trend in the use of animal labour over time. As more efficient technologies such as tractors and specialized agricultural machinery have been implemented and adopted, the need for animals to perform agricultural tasks has decreased. This transition to mechanized methods has allowed for increased productivity and resource efficiency.

4.2 Human muscle work

In Europe, human muscle work in agriculture has been consistently lower than the global average. This can be attributed to the region's advanced and modern agricultural technologies, which have been rapidly evolving since 1970. (Figure 2) The faster pace of industrialization in Europe compared to other parts of the world has contributed to a significant decrease in the reliance on human labour in agricultural activities.

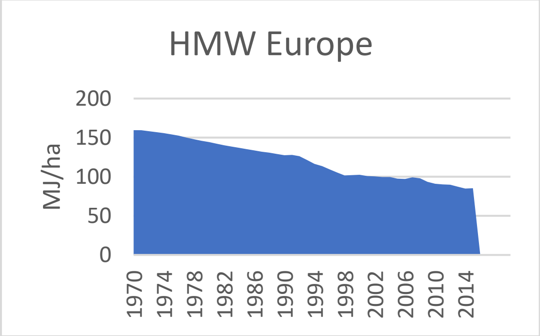

Figure 2 Human muscle work in Europe [1] [6]

The adoption of advanced machinery, automation, and precision farming techniques in European agriculture has led to increased efficiency, productivity, and reduced labour requirements. These technological advancements have enabled farmers in Europe to achieve higher levels of mechanization and automation, thereby reducing the need for human muscle work in various agricultural tasks.

4.3 Final Energy in Europe

The dominance of electricity in the graph showing MJ/ha for agriculture indicates that it has become the primary source of energy for farming operations worldwide. The growth in the use of electricity can be attributed to the increased mechanization and automation of agricultural processes, as well as the shift towards more energy-efficient and environmentally friendly energy sources.

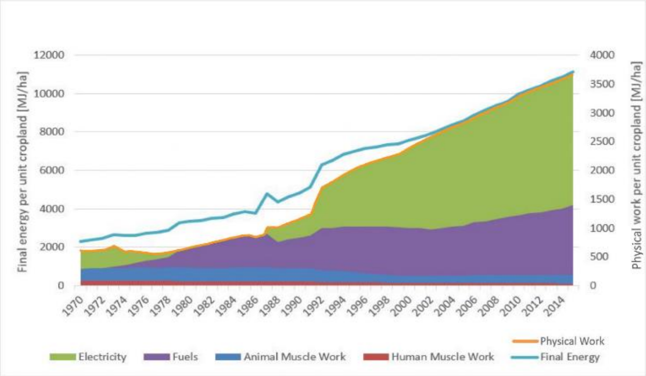

Figure 3 Final energy per unit of cropland and physical work per unit cropland in Europe

On the other hand, the graph also reveals the significant role liquid fuels continue to play in agriculture. The use of liquid fuels has also increased over time due to mechanization, expansion of irrigated lands, and increased transportation needs within the agricultural sector. However, the trend has shown signs of stabilization in recent years.

This stabilization can be attributed to several factors: improvements in the energy efficiency of machinery and equipment, an increased emphasis on renewable energy sources, changes in farming practices, and policy regulations aimed at reducing greenhouse gas emissions. Despite these changes, the continued presence of liquid fuels in the graph underscores their ongoing importance in many agricultural contexts, especially in areas where electric-powered options are not readily accessible or economically feasible.

4.4 Final Energy in the world

In the global context, the graph showing MJ/ha for agriculture also emphasizes the significant role of electricity in farming operations, driven by widespread mechanization and a shift towards more efficient and environmentally friendly energy sources. However, the trend of liquid fuel usage differs from that observed in Europe.

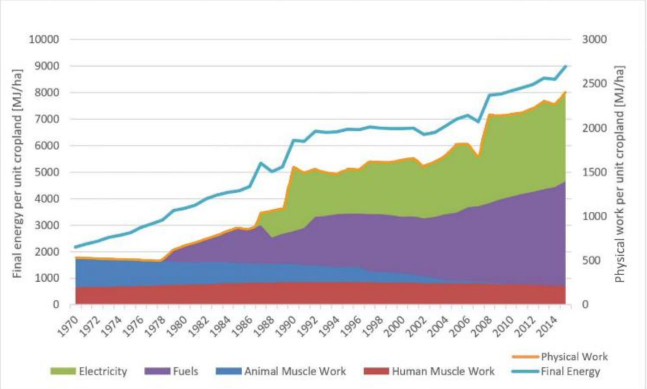

Figure 4 Final energy per unit of cropland and physical work per unit cropland in Europe

Contrary to the European trend, liquid fuel usage in global agriculture has continued to increase, reflecting the ongoing mechanization and intensification of farming in many parts of the world, especially in developing regions. Here, the accessibility, cost-effectiveness, and reliability of liquid fuels make them an essential component of agricultural energy consumption.

The graph also shows a larger gap between final and useful energy globally compared to Europe. This discrepancy can be attributed to the lower efficiencies found in many parts of the world. Europe has generally been at the forefront of developing and adopting more efficient engines and machinery, leading to higher energy conversion efficiencies. In contrast, in many other regions, older, less efficient equipment might still be in use, leading to a greater loss of energy during conversion, hence a larger gap between the final energy (total energy input) and the useful energy (energy converted into useful work). This emphasizes the potential benefits of improving energy efficiency in agriculture worldwide.

4.5 Comparison Land productivity Europe vs World

Let's now compare the graphs of 'Land Productivity in Agriculture' for Europe and the world at large. Here, 'million kcal/ha' refers to the energy output per hectare of cropland, measured in millions of kilocalories.

From the data, it's evident that both Europe and the world have seen an upward trend in land productivity over time. However, it's important to note that the ratio in Europe is almost double that of the global average. This indicates that European agricultural practices tend to yield higher energy output per unit of land area, demonstrating the efficiency of farming techniques used in this region.

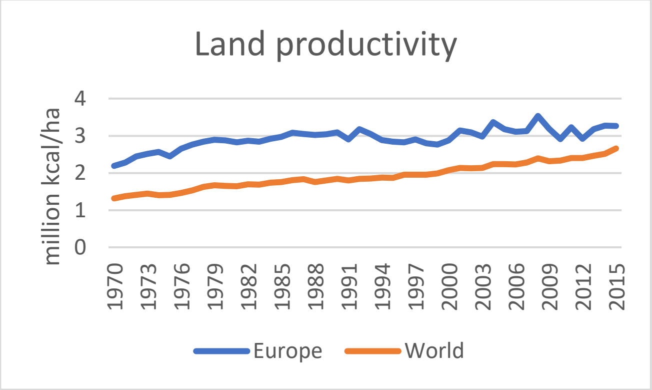

Figure 5 Land Productivity energy per unit of cropland Europe vs World

However, while this higher productivity can be beneficial in terms of meeting the growing demand for food, it also implies a higher level of resource usage, including energy, water, and fertilizers, which can have significant environmental impacts.

This is another reason why our project, aimed at creating a solar-powered poultry farm and vineyard, is so important. By harnessing renewable energy sources for farming practices, we can help to enhance agricultural productivity while also reducing the environmental footprint of these operations.

4.6 Comparison Labour Productivity Europe vs World

Figure 6 Labour Productivity Europe vs World

If the slope of labour productivity in agriculture (kcal of food/kJ of work) since the 1970s is steeper in the world compared to Europe, it suggests that the rate of productivity growth has been faster globally than in Europe over this period. This could be due to several factors.

Europe already had a high level of agricultural labour productivity by the 1970s due to its early and extensive adoption of modern farming practices. As a result, the potential for further rapid gains in productivity was somewhat limited—a phenomenon known as diminishing returns.

In contrast, many regions of the world had lower levels of labour productivity in the 1970s and therefore had more room for improvement. The global trend of increasing productivity likely reflects the adoption of modern agricultural technologies and practices in these regions.

This trend could also be attributed to the efforts by many countries to boost agricultural productivity as a means of improving food security and rural incomes. These efforts often involved policies and programs to promote the use of modern inputs, provide agricultural training and extension services, and improve rural infrastructure.

It's important to note, however, that while a steeper slope indicates faster productivity growth, it doesn't necessarily mean higher absolute productivity levels. As of now, labour productivity in European agriculture remains higher than the global average, even though its growth rate has been slower since the 1970s.

5. SOLUTION DESIGN

5.1 Design of a self-sufficient farm

The project aims to harness the potential of sustainable agricultural practices for a forward-looking and cohesive future Europe. Set in the scenic Vale Carneiro, Portugal, close to Alqueva, Europe's largest artificial lake, the initiative entails designing an innovative farm powered by renewable energy sources, specializing in raising chickens for egg production and cultivating a vineyard.

The objective of this solution was to identify an agricultural activity that is not only representative worldwide but also suitable for the specific conditions of Portugal. Wine production was chosen due to the region's favorable land and climate conditions, making it a relevant local industry. Meanwhile, poultry farming was selected as it is a common agricultural activity prevalent across various countries, thus allowing for a wider scope of application for the findings of this study. This dual focus ensured that the results could be informative and applicable both locally and globally in the agriculture sector.

Figure 7 Sketch poultry farm and vineyard

This project was developed based on real data acquired from a wine producer, "Adega do Calisto." This opportunity arose following a conference with the European organization "EubyLakes," held in October in Reguengos de Monsaraz. During this conference, valuable insights were gathered regarding the specific electrical demand of a vineyard that produces around 350,000 liters of wine annually. The use of this real-world data provides a foundation for our project, allowing us to tailor our sustainable and innovative solutions to the specific needs of an operational vineyard.

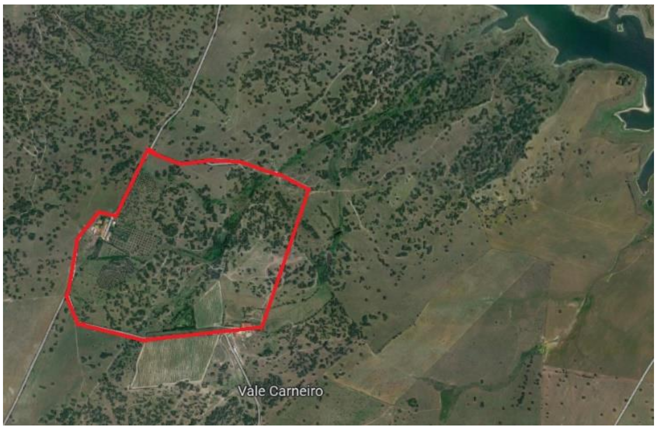

Figure 8 Sustainable farm Location (Portugal)

For the poultry farm portion of the project, an inventory was obtained from a chicken farm, allowing for the estimation of its energy demands. These demands were calculated based on its hours of operation throughout the year. The detailed inventory and operational data provided a comprehensive understanding of the farm's energy needs, enabling us to make accurate predictions and develop energy-efficient strategies tailored to the specific requirements of a functioning poultry farm.

5.2 Farm Demand

Once the electrical consumption patterns of both the poultry farm and the vineyard have been analyzed, we will proceed to aggregate these demands. This combined analysis will provide us with a comprehensive understanding of the annual energy demand for the entire operation. This crucial step allows us to accurately estimate the specifications of the photovoltaic plant needed to meet these energy demands sustainably.

By overlaying these energy requirements with the expected output of the proposed photovoltaic system, we can optimize the system design. The goal is to ensure the renewable energy source can meet the energy demands during peak periods, while also being cost-effective. Through this, we aim to create an agricultural operation that is not only productive and efficient but also environmentally sustainable, harnessing the power of renewable energy for a greener future.

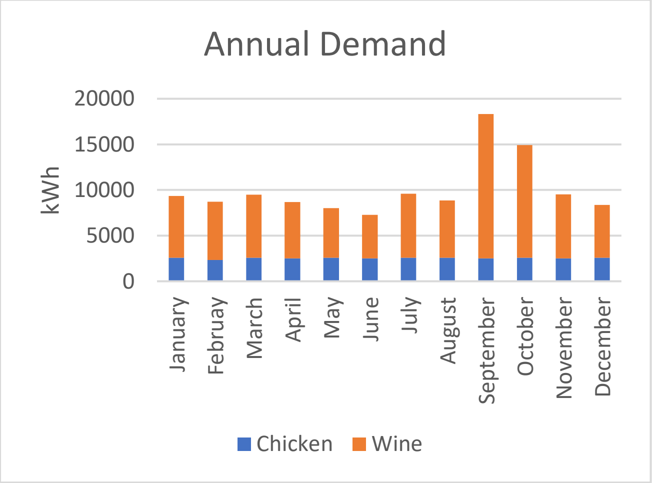

Figure 9 Annual demand in the whole self-sufficient farm

A graph is displayed showing the total energy demand when the poultry farm and vineyard are combined. As the vineyard activity increases from September to February, it is deemed critical to closely examine the energy profile during this period. Hence, we've decided to construct an hourly energy consumption profile for a day during the most intensive period of wine production, and another for a day during a less intensive period.

This approach allows us to better understand the temporal variation of the energy demand and will help guide our design of the photovoltaic system. It's critical to know not just how much energy is needed, but when it's needed, as the solar energy production fluctuates throughout the day. This detailed analysis will assist us in creating a photovoltaic system design that optimally matches the energy generation with the demand patterns.

The subsequent chart displays a power profile for a summer day, spanning from September to February. During this period, the vineyard's activity intensifies, resulting in a greater peak power demand. This profile is indicative of the energy requirements of the farm during its busiest season and helps in making more effective energy management decisions.

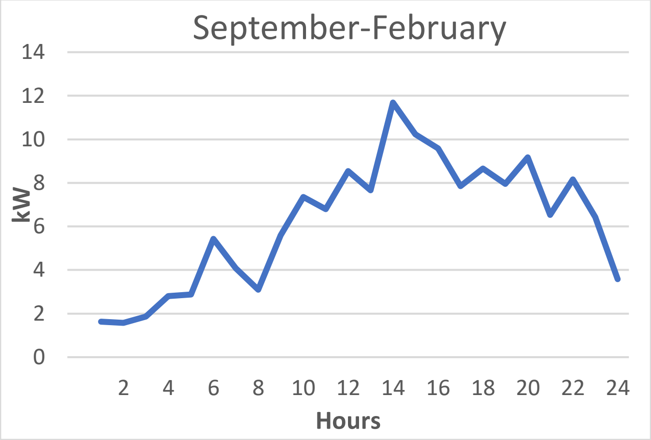

Figure 10 Power profile of a winter day

The following graph portrays a power profile for a winter day, which extends from March to August. This is a period of reduced vineyard activity, hence, the peak power demand is lower. This profile serves to illustrate the energy requirements of the farm during its off-peak season, which is critical for efficient energy management and planning.

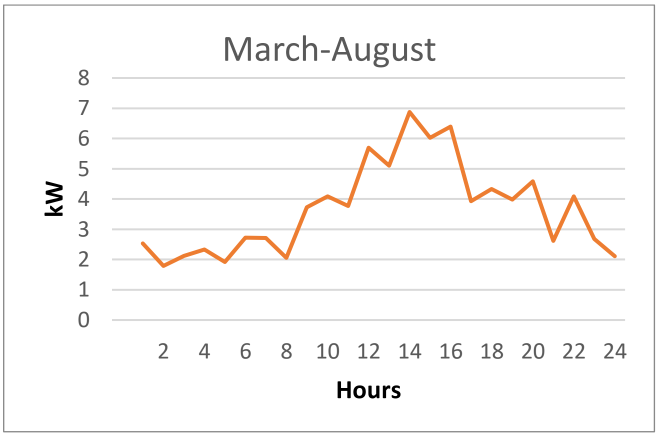

Figure 11 Power profile of a summer day

5.3 System Simulation

Once the controller of the microgrid under study has been implemented in the SIMULINK software, we proceed to simulate the system. To fully define the parameters of the simulation for this case study, we only need to determine the photovoltaic generation developed by the plant and the total duration of the simulation.

Figure 12 presents the normalization of the stable and unstable irradiance profiles utilized in this study. It can be seen that the time dimension of the irradiance profile is 288 seconds, thus simulating 24 hours of microgrid operation in 288 seconds.

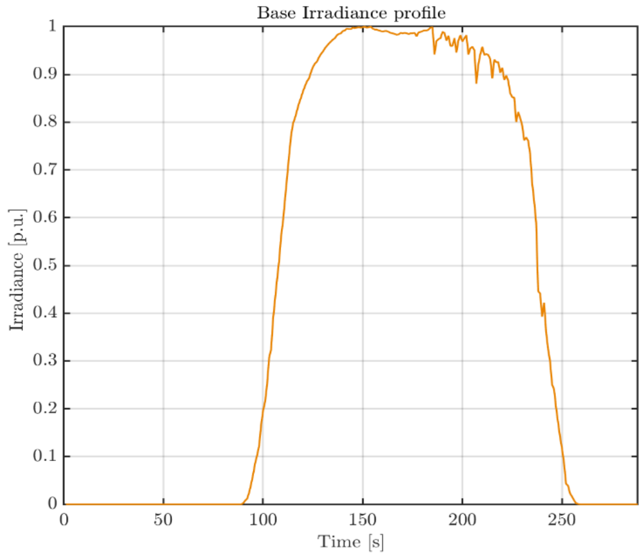

Figure 12 Irradiance profile normalized

This graph portrays the solar irradiance over a day at the photovoltaic plant. The y-axis shows the irradiance in per unit (p.u.), a dimensionless unit. This practice is common when dealing with variable conditions like solar irradiance, which can drastically change depending on the time of year and location.

Using the per unit (p.u.) system is beneficial in this context as it enables the adaptation of the same irradiance profile to both summer and winter seasons. This is crucial for year-round operations like a poultry farm and winery. In the summer, the peak solar irradiance reaches 1000W/m^2, while in winter this value reduces to a peak of 500W/m^2.

Normalizing the data provides flexibility to adapt to the changing solar irradiance throughout the year. This ensures that these changes can be accurately represented and responded to in the system model. It also aids in providing a more sustainable and reliable energy source for the operations, irrespective of the season.

The first simulation that we perform corresponds to a winter day when the solar irradiance is approximately 500 W/m^2. As you can see from the graph, during the night, the energy demand is covered entirely by the battery system. However, as the sun rises and the solar panels begin to generate power, both the photovoltaic system and the battery system work together to meet the farm's energy demand. This balance of power between the battery and the solar system is made possible by the use of a controller, which ensures that the sum of power from the battery and the photovoltaic system always matches the demand [17].

An interesting phenomenon to note is that when the solar energy production exceeds the energy demand, the surplus energy is used to recharge the battery system. This energy storage ensures a buffer for times of lower irradiance or during night hours when the photovoltaic system isn't generating power. As the solar irradiance starts to decrease, such as during sunset or cloudy periods, the battery system then kicks in, discharging stored energy to meet the demand.

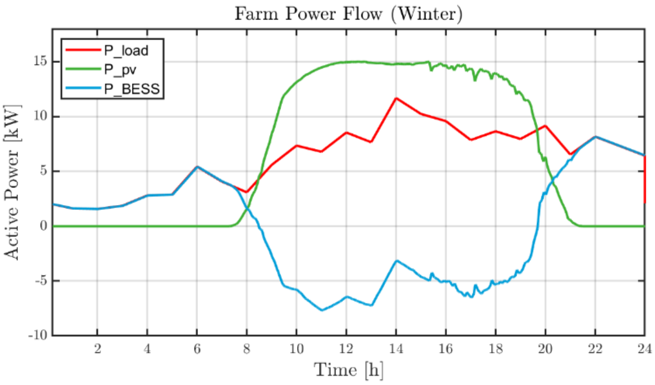

Figure 13 First simulation in a winter day

This step will now go into the process of battery charging and discharging, taking the simpler case of a winter day simulation as an example. Over the course of the day, the battery charges and discharges, but it doesn't reach its maximum capacity during charging hours. This process is vividly illustrated in the subsequent graph.

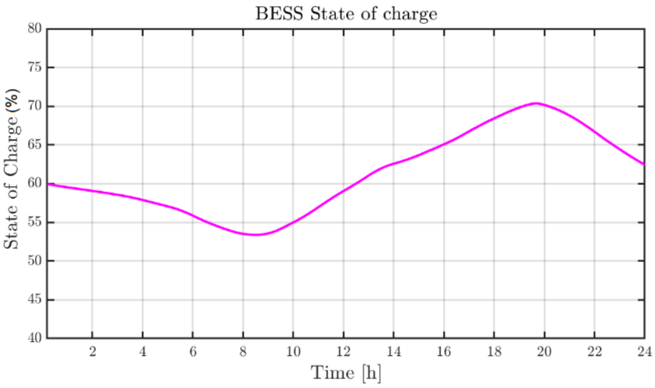

Figure 14 Case 1 BESS state of charge

The second simulation represents a summer day when the peak irradiance is 1000W/m^2. Until about 8 am, the behavior of the battery and demand is the same as on a winter day. However, the power production from the photovoltaic plant is significantly higher here. By 9 am, the power generated by the plant exceeds both the demand and the battery's charging power. At this point, there is a slight drop in power because the photovoltaic plant has regulated its output.

Then, around six in the evening, once the battery is fully charged, we can observe a change in the photovoltaic plant's behavior. It limits its power output and adjusts it directly to match the demand. This adjustment is crucial to prevent overproduction and ensure the efficient use of generated power, illustrating the adaptability of renewable energy systems to changes in environmental conditions and power demand [18]. The use of control systems to manage power production based on demand and battery status is a critical component of sustainable and efficient energy management.

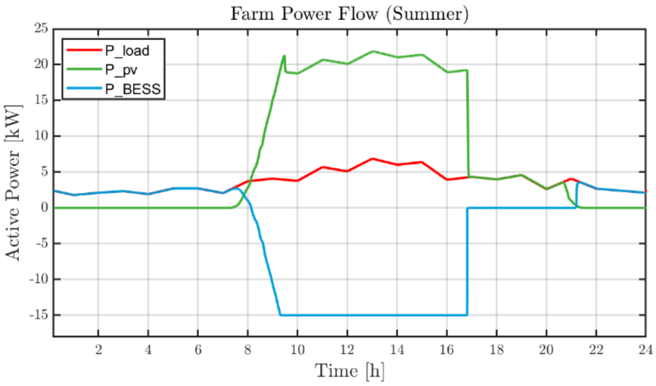

Figure 15 Second simulation in a summer day

Next graph shows battery charging on a summer day. We can observe how the battery discharges during the night while conversely, during the day, it's being charged. At a certain point, the battery completes its charging cycle, reaching its maximum capacity. As long as the photovoltaic production continues to cover the demand, the battery's capacity remains constant at 100%.

This behaviour of the battery underscores the importance of storage systems in renewable energy-based setups. Notably, during periods of excess energy production, the energy is not wasted but stored for use during periods of lower production or higher demand. This is especially important for solar power systems, where energy production varies significantly throughout the day. Thus, efficient battery management plays a crucial role in ensuring the continuous availability of power and the overall sustainability of the system. It further highlights the necessity of a well-designed control system to manage the interplay between power production, demand, and battery charge levels, optimizing system performance and longevity.

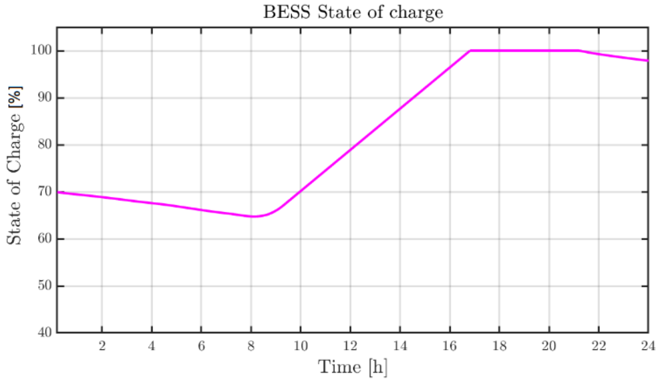

Figure 16 Case 2 BESS state of charge

6. CONCLUSIONS

The conclusions drawn from the case study emerge with some notable differences found between the European analysis and the global analysis.

Beginning with animal work, the global decrease lags behind Europe by a decade. However, by 2015, both held the same ratio of 200 MJ/ha. In terms of human muscle work, the decline in Europe is more pronounced, but the world at large follows a more moderate pace. For instance, in the last decade, Europe has a MJ/ha ratio that's 60% less than the global average. Electricity usage in Agriculture has stagnated globally since the '90s, while in Europe, growth is significant, reaching 3600 MJ/ha today. This represents a 40% increase compared to global levels.

In terms of liquid fossil fuel usage, the figures are more comparable in absolute terms. Nevertheless, it can be observed that European policies have effectively halted its increasing use. The next step would be to reduce it.

The study's finding related to work is highly relevant. To produce 1MJ/ha of physical work, it takes 3.6 MJ/ha of final energy (current global rate) and 3 MJ/ha of final energy (current European rate). Therefore, there's still a long way to go to reduce this proportion, beginning with reducing fuel usage and ensuring that electricity production becomes as sustainable and efficient as possible.

A similar case to liquid fuels occurs with the use of fertilizers and pesticides. At the European level, usage has stabilized at 100kg/ha, whereas globally we have 140 kg/ha currently.

All of these factors previously discussed are reflected in land productivity, which is clearly seen to be twice as high in Europe. This is further evidenced in labour productivity, with the European ratio being four times bigger than global scale.

The conclusions of our solution, focusing on poultry and wine production in the Alentejo region of Portugal, yields significant insights into the potential for self-sufficiency and sustainability in agricultural practices.

Building upon the outcomes of this project, potential future research could involve a detailed analysis of a specific country, examining its data from recent years and comparing it with the broader European context. This targeted study could provide further insights into national trends and variations in agricultural practices and energy usage. It could also serve to highlight potential region-specific strategies for transitioning towards more sustainable agricultural systems.

As for the proposed renewable energy solutions, the integration of an emergency diesel generator could be a considered enhancement for the system. This modification would provide an added layer of resilience, ensuring that energy demands are met even in periods of high demand or reduced solar input.

Additionally, the electrical circuit could be redesigned to accommodate the simultaneous operation of both the diesel generator and the solar panels. Such a hybrid system could effectively address potential energy shortfalls during the day, further enhancing the reliability and flexibility of the system. By continuously refining the design and integration of renewable energy systems, we can ensure that they become ever more efficient and adaptable, enabling agriculture to increasingly move away from dependence on fossil fuels and towards a sustainable future.

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