Heating or transporting?

Energy use in greenhouse's aquaponics in continental climate and the energy demand of transportation from Mediterranean regions

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Abstract: Greenhouse production in Mediterranean regions is a very profitable business. Nowadays European supermarkets are full of agricultural products from this area. The newest trend is combining aquaculture and hydroponics: fish and vegetable production in one system. It is also possible to produce these products in greenhouses in Continental climate, but it needs much more energy. However, a question has arisen: which production type needs more energy: produce products in Mediterranean regions and transport it to the heart of Europe, or produce it in Europe? This paper compares these two possible ways, building up a system dynamic model for an aquaponics greenhouse production in a Continental climate.

Keywords: location decision, aquaponics climate simulation, energy demand of transport, heating demand,

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1. Introduction

The production of agricultural products tends to break away from the limitations through climate, soil and sunlight. Huge glasshouses cover the rural regions of Spain; the plants grow in hydroponics without any soil or natural fertilizer, illuminated with artificial light. This trend reached the fish breeding branch, the aquaculture left the natural ponds and the ocean and moved into tanks. Aquaponics arises from combining the two systems. The waste water from the fish tanks will be led into a hydroponic system, where the bacteria in the biofilm of the growing media transforms the by-products of the aquaculture into minerals, which will be used by the plants. The clean water will be recirculated into the fish tanks.

Aquaponics is held to be the food-production of the future as a source of self-sufficiency. The sustainability of aquaponics system needs a lot of research. One very important aspect is the energy-demand of such systems which is dependent primarily on the climate of the particular location.

2. Problem definition:

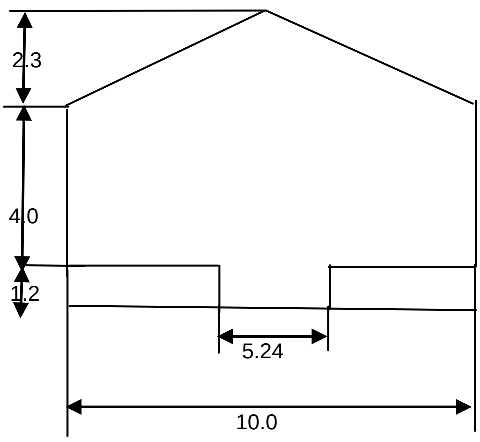
The aquaponics system was developed in a tropical climate, where all year round, intensive, low energy use production was possible due to environmental conditions. Such systems are also operated in a colder climate (with greenhouse technologies), but it is necessary to ensure the suitable inner climate and light conditions, which we need energy for. Energy can be provided either with active or passive methods. This paper investigates the energy use of such an aquaponics system compared with the traditional system, where vegetables and fish are transported to areas with a continental climate (in our case Pécs) from Mediterranean or subtropical areas, where heating is not required, but the greenhouse or screenhouse technology is used in order to protect the cultivated plants and fish from weather's influences, pests, etc. If the energy needed to support the inner climate of a greenhouse and the production system is larger than the energy use for the transport of the same product – assuming that the energy use for running the system without heating and the volume of production is the same for both sites - than we can conclude that from an energetic point of view it is not worth to install an aquaponics system in the researched area.

3. The greenhouse model with aquaponics

The goal of a model is a simulation of a greenhouse climate in order to estimate the heat which is necessary to maintain an optimal climate in the greenhouse. The simulation of this hypothetical system is based on functioning aquaponics and hydroponics systems (Rakoczy et al., 2006). The results of the simulation will be used to size experimental aquaponics greenhouses in Hungary.

Table 1 The properties and dimensions of the aquaponics greenhouse

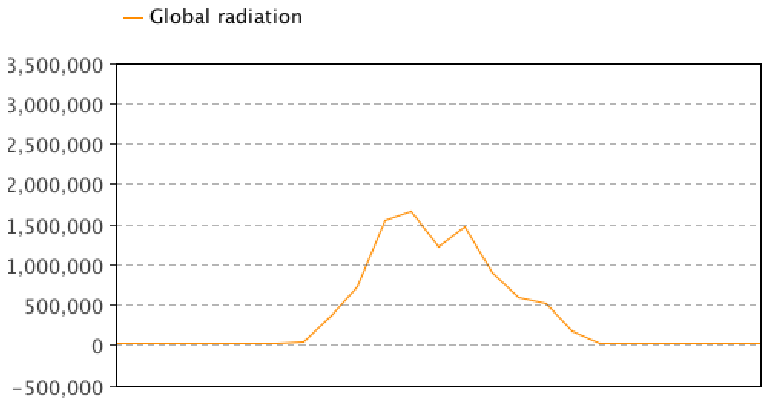
Length (m)	20
Width (m)	10
Gutter high(m)	4
Ridge high (m)	6.3
Area floor (m^2)	200
Area glazing (m^2)	321
Volume greenhouse (m^3)	1545
Volume air (m3)	1030
Area plant beds (area gravel) (m^2)	150
Volume gravel (m^3)	40
Density gravel	250
Total surface area gravel (m^2)	13500
Specific surface gravel m^2/m^3	300
Mass gravel (kg)	810 000
Volume fish tank(m^3)	33
Deepness fish tank (m)	1.2
Area water (m^2)	27.5
Infiltration loss (l/h)	2



The production of the system is estimated according to the data of Rakoczy (Rakoczy et al., 2006). In the first simulation we grow the fish tilapia and lettuce; this is a common configuration in commercial systems. Tilapia is a warm water fish, but it is cultivated in the USA in temperate climate too, because it can tolerate crowding and the fish tank environment. If we succeed in ensuring the optimal climate in the greenhouse, we can harvest 92 kg tilapia and 600 lettuces (0.3-0-4 kg a piece) per week. The requirements for the temperature of the greenhouse plant beds are given not by the lettuce, but by the biofilm. The bacteria in the biofilm need a temperature of 25-30 ^{0}C. The biofilm performs optimally in filtering the waste of fish and mineralizing the toxic ammonium into nitrites and nitrates if the temperature is within this range. The lethal temperature of the biofilm is 0 ^{0}C, but the activity of the biofilm is halved at 18 ^{0}C what can lead to the collapse of the small ecosystem. The optimal water temperature growing tilapia is 28-30 ^{0}C, the lethal temperature is 16 ^{0}C. The lettuce is the most resilient, there are several sorts which can tolerate the temperature range between 6-25 ^{o}C, the minimum of the gravel bed for them is 6 ^{o}C. The source of the climate data is the weather station of the

University of Pécs (http://joido.ttk.pte.hu/). Pécs is located in Central-Europe, latitude 46., it is in the 6. USDA climate zone, the climate is continental, with a little Mediterranean influence. External temperature and global radiation data were collected in Pécs, Hungary on a minute basis, and authors generated hourly data from both. Figure 2. demonstrates the global radiation for 29. February 2012. in Pécs from 0 to 23 hours.

Figure 1 Global radiation (in W/m³) on a winter day in Pécs, where the vertical axe is the time variable from 0 to 23.

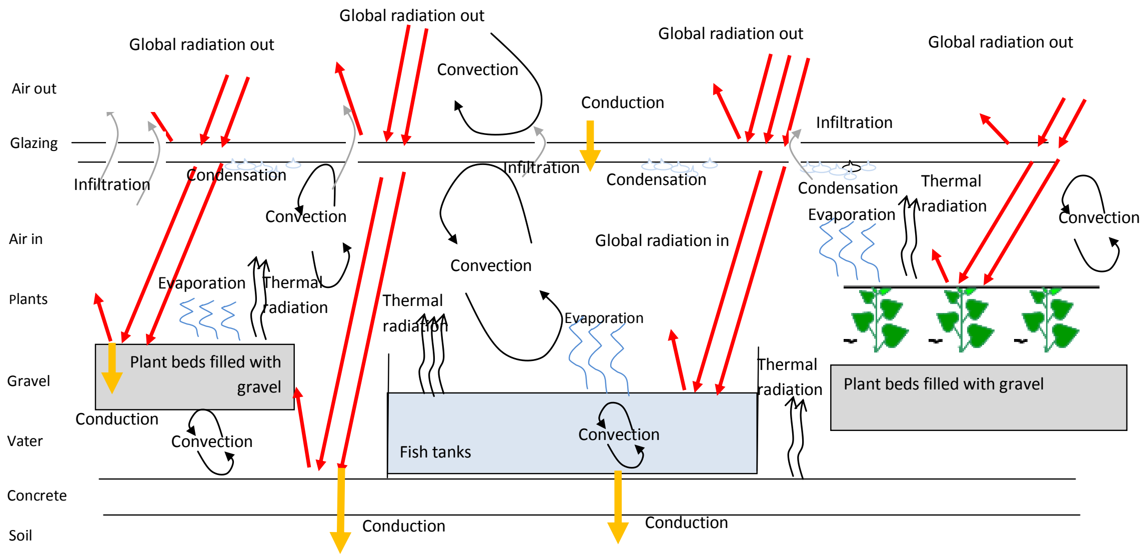


Source: Own elaboration.

3. Heat transport in an aquaponics greenhouse

The heat transport fluxes in an aquaponics greenhouse are summarized on Figure 2.

Figure 2. Energy and water vapor fluxes in a common aquaponics greenhouse (without heating and ventilation)

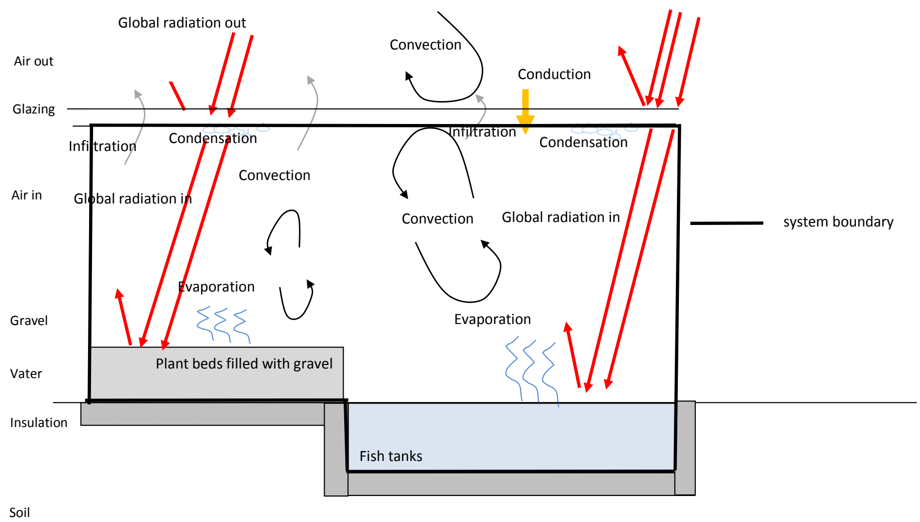


Source: Fitz-Rodrígueza et al 2010; Zhou et al 1998

The goal of our current simulation differs from the simulations described in various papers. We do not explore the efficiency of control mechanism and heating-cooling systems in order to ensure the continuous production. We need only the global heating demand in order to compare the aquaponics production with the energy demand of transport. In temperate climate the main energy use is for heating. The "greenhouse effect of a greenhouse", the overheating in summer which is a main problem in warm climate can be usually solved in Pécs by proper mechanical ventilation. We assume that the chosen lettuce sort does not demand artificial lightning.

In order to decrease the heating demand we have redesigned and simplified the aquaponics system: the fish tank is in the soil, the foundation and the fish tank is well insulated, the whole area is covered with gravel beds. We do not consider the heat loss towards the soil, the insulation makes it negligible. The heat loss due to evaporation will be considered in the energy balance of the gravel bed and the water in the fish tanks. The evaporated water condenses on the glazing of the greenhouse, most of the heat will be lost due to the glazing, so we do not consider the condense heat in the energy balance of the greenhouse.

Figure 3 The heat fluxes in the aquaponics greenhouse of the simulation



If we consider the aquaponics glasshouse as a closed container (Roy et al., 2002), and do not consider the thermal stratification of the heat storage masses, we can describe the thermal interactions in an aquaponics greenhouse with a following energy balance equation.

$$\sum_{j=1}^{l} c_j \rho_j \frac{t_j^k - t_j^{k-1}}{\Delta\tau} V_j = \sum_{j=1}^{m} g I_j A_j - \sum_{j=1}^{n} A_j U_j \left(t_i^{k-1} - t_e^{k-1}\right) - \rho_{Air} V_{Air} n c_{Air} \left(t_i^{k-1} - t_e^{k-1}\right) / 3600 \qquad (1)$$

The energy balance equation expresses the equilibrium of the heat flux (W) flowing in the time $\Delta\tau$ into the various j^{th} heat storage masses with the equilibrium of the global radiation gain, the heat loss due to transmission and infiltration (W).

Table 2 Abbreviations

c_j	the specific heat of the j^{th} heat storage mass (gravel or water), J/kgK
ρ_j	density of the j^{th} heat storage mass heat storage mass (gravel or water) kg/m^3
t_j^k	temperature of the j^{th} heat storage mass in time step K
t_j^{k-1}	temperature of the j^{th} heat storage mass in time step K-1
$\Delta\tau$	duration of the time step, second
V_j	volume of the of the j^{th} heat storage mass, m^3
g	the coefficient of the permeability of the total solar radiation energy of the glass
I_j	intensity of the radiation reaching the j^{th} glazing, W/m^2, (differentiation according to the orientation)
A_j	area of the j^{th} glazing , m^2, (differentiation according to the orientation)
U_j	overall heat transfer coefficient of the j^{th} glazing), W/m^{2}K, (differentiation according to the orientation)
t_i^{k-1}	internal temperature in the time step k-1, K
t_e^{k-1}	external temperature in the time step k-1, K
ρ_{Air}	density of air, kg/m^3
V_{Air}	volume of air m^3
n	infiltration rate, 1/h
c_{Air}	specific heat of air J/kgK
σ	the evaporation coefficient of water kg/m^{2}h
r_{Water}	latent heat vaporization of water evaporation
x_s	absolute humidity at saturation at water surface
X	absolute humidity of air kg water vapor/kg air
r_{Water}	evaporation heat of water

The energy balance equations of the water in the fish-tank and the gravel bed as of masses with heat storage capacity and evaporation.

$$c_m \rho_m \frac{t_m^k - t_m^{k-1}}{\Delta\tau} V_m = a_m g I_{level} A_m - \alpha_{level} A_m \left(t_m^{k-1} - t_{Air}\right) - \frac{1000}{3600} \sigma A_m \left(x_s - x\right) r_{Water} \qquad (2)$$

Where the “m” index is the current medium, the “level” index is the radiation intensity of the horizontal surface and the convection heat transfer coefficient.

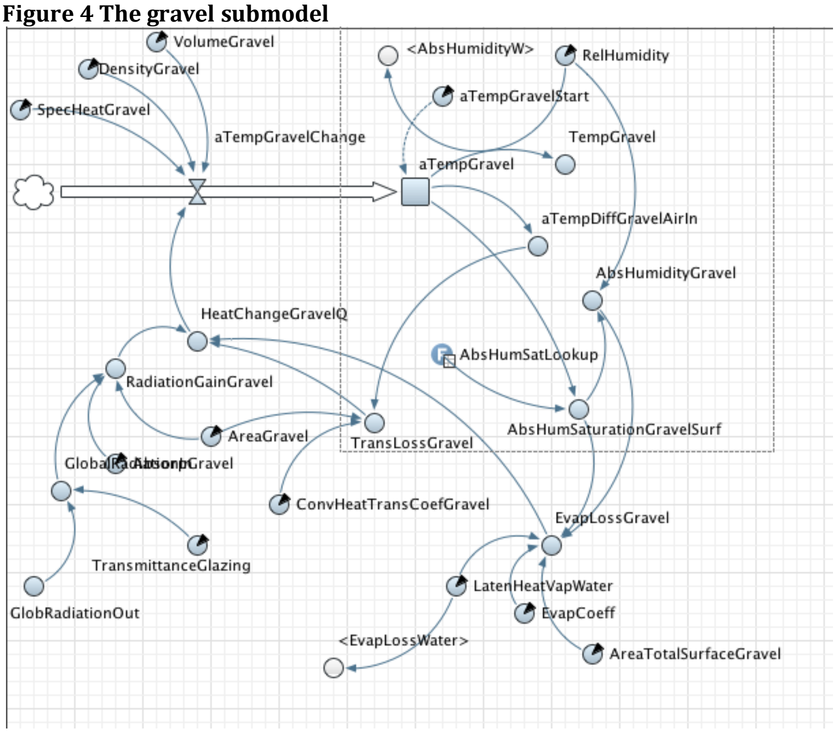
4. The dynamic model of the continental aquaponics system

AnyLogic 6.7.1 was used for the model simulation. A system dynamic model has been created for the simulation of the greenhouse (aquaponics) system. The model consists of three main modules: the gravel, water and air simulation.

The temperature is the stock variable in each submodel. Flow variables change with the used medium for heat change, which is influenced by the direct or indirect gain from the global radiation and by the loss due to convection, evaporation, transmission and infiltration.

The gravel submodel is the following:

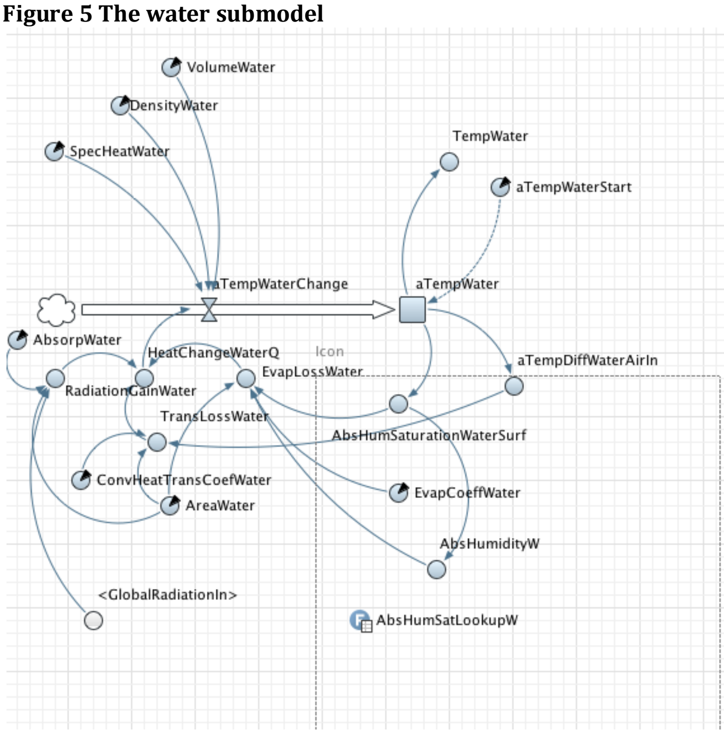
Figure 4 The gravel submodel



The heat change of the gravel is increased by the internal radiation gain. The heat will be decreased by the transmission loss and by the evaporation loss, since the gravel is always wet due to the circulation of water. The gravel heating switches on when the gravel temperature goes below 25 ° Celsius in order to maintain optimal climate for the bacteria in the biofilm. The temperature will be calculated from the heat change.

The water system model is the following:

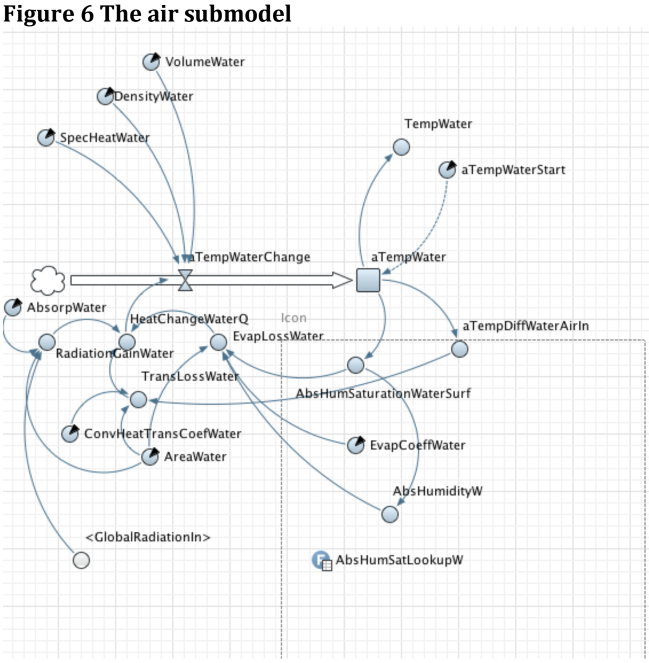
Figure 5 The water submodel



The structure of the water submodel is the same as the structure of the gravel submodel. The water heating system switches on if the water temperature goes below 25 ° Celsius. The accumulated heating quantity is collected in the accuWaterHeat stock variable.

The air submodel is the following:

Figure 6 The air submodel



The heat gain of the air is equal to the transmission and evaporation losses of the water and gravel. The heat of the air will be decreased by infiltration and convection. If the internal temperature of the air goes below 7° Celsius the air heating system switches on. Total heating quantity is collected in accuAirHeat stock variable.

5. Results

The total energy used 122,114 Megajoules for one year with a cold winter. The submodel's energy uses are the following:

Gravel heating 109,290 Megajoule

Water heating 12,823 Megajoule

Air heating 0 Megajoule (did not switch on at all.)

These are the first simulation runs. At this stage the gravel bed is not covered by plants (from a simulation point of view.) At a later stages other vegetable – fish combinations will also be simulated.

6. Comparison of the energy needs

In this section the energy need of the availability of the products in the case of local and remote (Mediterranean) production will be compared. It is vital for the comparison of the energy need for the two different methods (greenhouse aquaponics in Mediterranean and Continental climate) to know the transportation cost of Mediterranean goods to the heart of Europe do decide whether it is worth to plant an aquaponics system in a given area.

First, the transportation of one kilogram of goods (fruits, vegetables, fish, etc.) will be determined. According to Speilmann and Scholz (2004) the energy consumption (MJ/tkm) of a vehicle involved in transportation varies between 1.54 and 3.08 MJ/tkm.

Table 1: Final energy consumption for vehicle travel. The energy values are based on the lower heating values of diesel fuels (42.8MJ/kg diesel)

Mode of Transport	Transport Service	Diesel Kg/tkm	Electricity [1] KWh/tkm	Final Energy Consumption MJ/tkm
Rail	Average CH		0.062	0.22 [2]
	Average RER	0.002	0.040	0.23 [2]
Road	Lorry 16t CH	0.072		3.08
	Lorry 28t CH	0.050		2.14
	Lorry 40t CH	0.036		1.54
	Lorry 16t RER	0.089		3.81
	Lorry 32t RER	0.038		1.63
Water	Barge	0.009		0.38

[1] The presented energy figures account for a transformation loss of 15%.
[2] The final specific energy consumption for electric railways in Europe is assumed to be lower than the Swiss average. Thus, the higher specific fuel consumption of diesel locks which are still in operation in Europe is compensated for.

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Source: Spielmann, Scholz (2004) p.x.

We will use – for the comparison with the energy use of an aquaponics greenhouse in Pécs – the minimum energy consumption of road transport, which is 1.54 MJ/tkm for 40t CH lorries. The distance between Almeria, Spain and Pécs, Hungary is roughly 3000 km (assuming that the lorries use the freeways).

$$1.54\,\frac{MJ}{tkm} \cdot 3000km \cdot 40t = \quad 4620MJ$$

If the lorries are fully loaded (40t), the energy use for the 40ton lorry that transports goods from Almeria to Pécs is roughly 184,800 MJ. For one ton of goods, that comes to 4620 MJ.

There is an assumption, based on (Heidelberg, 2011) that a 40 ton lorry does not always carry 40 tons of commodity. This paper indicates that there is an average of 50% utilization (Heidelberg, 2011, p.21). To make sure that our paper's results are not over exaggerated, we will use a 60% utilization rate. Therefore, the 184,800 MJ has to be spread to not 40 tons, but 40 tons 0.6 = 24 tons.

$$\frac{184{,}800\ MJ}{24\ t} = 7700\ \mathrm{MJ/t}$$

The energy consumption (even with very conservative calculations) for one ton of good transported from Almeria to Pécs is roughly 7700 MJ/t.

Second, the Continental greenhouse energy consumption should be calculated. For the greenhouse example the yearly production of vegetable is the following:

For one week the salad is 600*0.35=210 kg. For a year: 210*52=10,920 kg.

For one week the fish is 92 kg. For a year: 92*52=4784 kg.

We do not differentiate the two types of produce, therefore we summarize the quantities: 10,920 kg + 4784 kg = 15,704 kg a year.

122,114 Megajoules are needed for one greenhouse per year. Since one greenhouse accounts for 15.704 tons of goods yearly, we can determine that

$$\frac{122{,}114\ MJ}{15.704\ t} = 7775.98\ \mathrm{MJ/t}$$

7775.98 Megajoules are needed for the *production* of 1 ton of goods in a local greenhouse. This is practically the same amount (less than 1% difference compared to 7700MJ/t) of energy that is needed for only the *transportation* of goods from Spain.

7. Summary

This paper analyses two different business models for agricultural supply of a region. The first is a Mediterranean greenhouse production with transportation; the second is a Continental greenhouse production with heating energy usage. The place of the Continental production is Pécs, Hungary.

International references were used for calculating the transportation cost in the first case, and a system dynamic model was created to simulate the total heating cost of the Continental greenhouse production.

Our results support that from an energy point of view practically there is no difference between the two cases. Additionally, it should be emphasized again, that this examination does not consider externalities, energy and food independence, and other important factors.

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