

Energy Use in Greenhouses in the EU

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Contributor: Bas Paris , , Athanasios Balafoutis , Konstantinos Vaiopoulos , George Kyriakarakos , Dimitris Manolakos , George Papadakis

High energy systems, which are more dominant in northern Europe, are generally heavily climate controlled and energy use is dominated by heating and cooling processes, while low energy systems, which are dominant in southern Europe, show a mixture of energy uses including heating, cooling, irrigation, lighting, fertilisers, and pesticides.

energy-use in agriculture

fossil-energy-free technologies and strategies

FEFTS

greenhouses

1. Introduction

In the EU, greenhouse structure and cultivation show considerable variation, ranging from complex energy intensive structures that heavily regulate the indoor climate to simple structures that resemble open-field practices. This variation is dependent on a variety of factors, including, but not limited to, local climatic and socio-economic conditions ^[1]. According to the FAO, an estimated 405,000 hectares of greenhouses are spread throughout the EU ^[2], a figure that includes both glass and plastic covered structures. By contrast, data from Eurostat provide an overview of the area of vegetables, flowers and permanent crops under glass in the EU-27 from 2005–2013, highlighting that there are around 135,000 hectares of glass covered (excluding plastic covered) greenhouse cultivation in the EU ^[3].

Greenhouse agricultural production is generally seen as one of the most intensive parts of agricultural production ^{[4][5]} as compared to energy use in open-field agriculture ^[6], however the role of greenhouse agriculture in the European food systems is not well-documented ^[1], while a small number of studies have been conducted that document energy use in greenhouse production. In 2013, the European Commission published a report on greenhouse production, however this only includes only some minor energy use statistics ^[5]. Campiotti et al. (2012) investigate some of the energy parameters in the greenhouse sector in four European countries ^[7]. Mohamed et al. (2017) investigate the energy profile of greenhouses in Cyprus ^[8], while Wageningen University releases an annual report monitoring energy use within the Dutch greenhouse sector ^[9]. Regarding geography, the Netherlands in particular has the largest and most relevant energy use data available ^[9]. Nikolaou et al. (2021) investigates energy parameters in greenhouse tomato and cucumber production in semiarid Mediterranean areas ^[10]. Other studies that look at agricultural production or energy use in the agricultural sector generally provide no data on energy use in greenhouses specifically ^[11].

In this context, where it is clear that greenhouse cultivation is a significant energy consumer but there is relatively little data available, and taking into account the implementation of EU climate targets and its farm to fork strategy in agriculture, it is apparent that there is a need to move towards sustainable production practices. In order to understand the future of greenhouse production in the EU and how they can contribute to a sustainable transformation of the agricultural systems, it is necessary to understand the energy use in greenhouses.

2. Greenhouses in the EU and Their Energy Use Parameters

Greenhouses are complex structures which aim to create ideal conditions for plant growth and production throughout the year, by controlling temperature, humidity, water, light, and carbon dioxide ^[12]. There are different types of greenhouses currently in operation in the EU, ranging from intensive structures that heavily regulate the internal environment to those that are solely plastic sheet covered structures in which production inputs are similar to open-field crops ^[5]. Over the last two decades, the technology associated with the construction of and agricultural production within advanced greenhouses has progressed considerably with significant changes in design, materials, agricultural techniques, etc. Consequently, the potential yield in 'technology intensive' greenhouses has seen dramatic increases, for instance, what is considered a 'good' tomato yield has increased from 100 tonnes per hectare to 600 tonnes per hectare in recent years ^[13].

There are a variety of options for heating a greenhouse, including air heaters, central heating through pipes, boilers, cogeneration, natural gas, electricity, heat pumps ^[14]. Energy sources vary, with small systems often running on direct fossil fuels, such as gas or oil, while larger systems may run on cogeneration/combined heat and power from power plants, or geothermal heat pumps. It is important to note that a large proportion of greenhouses, especially in Southern Europe, are not heated, while in temperate and northern European countries greenhouses often have large heating requirements. Conversely, there are a number of options for cooling a greenhouse, including shading, whitening, natural, mechanical or evaporative cooling/ventilation. One or a combination of these are utilised in areas that have high average temperatures for parts of the year ^[5].

All production in greenhouses requires irrigation for which there are a variety of systems, generally powered through fossil fuels directly or via the electricity network ^[5]. Other areas that consume direct energy include lighting and machinery use. Greenhouses generally are also dependent on a number of indirect sources of energy; energy that is not directly used in agricultural production but can clearly be assigned to the agricultural sector. Indirect energy use includes energy use associated with the building of greenhouses and greenhouse machinery, as well as energy embedded in the production of fertilizers and pesticides ^[15].

There are a number of trends and parameters that affect the energy inputs of greenhouses. Multiple studies highlight that older systems are generally less energy efficient and require higher energy inputs per output ^{[16][17]}. Geography and climate conditions also clearly play an important role ^[18], while the type and philosophy of agricultural practices and techniques-conventional, organic, conservation, soilless cultivation, hydroponic, etc., employed in greenhouses are also likely to impact energy inputs. In practice, greenhouse systems in the EU vary

significantly ranging from commercial large-scale systems to small-scale subsistence systems and their design and structure varies considerably, having large implications on energy use and energy sources [\[5\]](#).

The extent of greenhouse production per country is not well documented. For most EU countries, other than the Netherlands, there are rough estimates on the extent of greenhouse cultivation, in particular regarding greenhouses with a low technological profile. Eurostat used to provide an indicator on the area of vegetables, flowers, and permanent crops under glass EU-27 (ha), this has now been discontinued. Based on the data presented in **Table 1**, from Eurostat, the countries cover around 72% of the total area under glass in the EU.

Table 1. Area of vegetables, flowers, and permanent crops under glass EU-27 (ha) [\[19\]](#).

Country	2005	2007	2010	2013
Belgium	2140	2120	2060	1800
Bulgaria	900	1140	1090	1080
Czechia	180	190	0	0
Denmark	450	470	460	400
Germany (until 1990 former territory of the FRG)	3370	3430	3170	3110
Estonia	60	60	40	40
Ireland	60	30	60	180
Greece	4670	5340	4290	4730
Spain	52,170	52,720	45,700	45,200
France	9620	9790	:	11,190
Croatia	:	250	410	500
Italy	28,640	26,500	39,100	38,910
Cyprus	420	430	450	420
Latvia	110	80	50	40
Lithuania	1010	450	310	330
Luxembourg	0	10	0	0
Hungary	1910	1760	1960	2260
Malta	70	70	80	100

Country	2005	2007	2010	2013
Netherlands	10,540	10,370	9820	9330
Austria	290	580	620	720
Poland	7170	7560	6630	8080
Portugal	2310	2220	2360	2490
Romania	2790	3250	3020	3300
Slovenia	170	180	170	160
Slovakia	250	190	150	100
Finland	450	440	420	400
Sweden	420	180	200	260
Total	130,170	129,810	122,620	135,130

greenhouses. Acta Hortic. 2017, 137–144.

2. Baudoin, W.; Nersisyan, A.; Shamilov, A.; Hodder, A.; Gutierrez, D.; Nicola, S.; Chairperson, V.;

3. **Energy Use for Greenhouses in the EU Per Country and Crop**

European Countries Food and Agriculture Organization of the United Nations Plant Production and Protection Division Principles for Sustainable Intensification of Smallholder Farms; FAO: Rome, Italy, 2017; ISBN 978-92-5-109622-2.

3.1. **Overview**

3. Eurostat Area under Glass by NUTS 2 Regions. Available online: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_lus_unglass&lang=en (accessed on 14 December 2021).

4. Pittarelli, P. Organic Greenhouse Production: Towards an Agroecological Approach in the Framework of the New European Regulation—A Review. Agronomy 2020, 10, 72.

Table 2. Range of energy consumption per category in EU greenhouses (%).

5. EGTOP. Final Report On Greenhouse Production (Protected Cropping); EGTOP: Brussels,

Energy Consumption per Category	Range of Total Energy Consumption
Heating and cooling	0–99%
Irrigation	1–19%
Fertilizers	1–27%
Pesticides	0–6%
Lighting	1%

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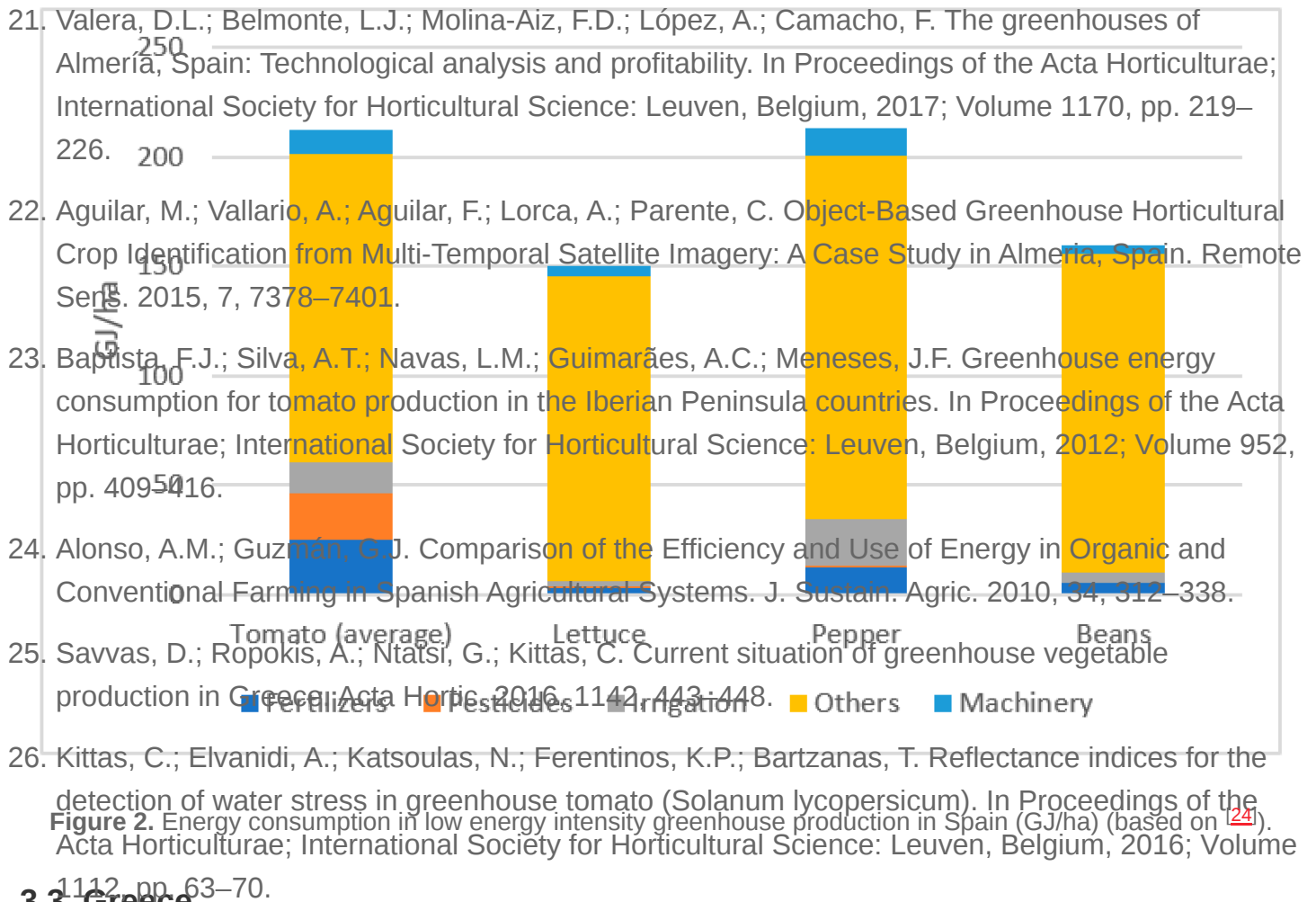
3.2. **Spain**

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19. Eurostat Crops under Glass: Number of Farms and Areas by Agricultural Size of Farm (UAA) and Size of Crops under Glass Area. Available online: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_poglass&lang=en (accessed on 29 April 2022).

Figure 2. Energy consumption in high energy intensity tomato greenhouse production in Spain (GJ/ha) (based on

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3.3. Greece

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34. Lambregt, F.; Bakker, R.; Van Doorn, M. Intensive Horticulture in the Netherlands and Europe, per Berenschot Group B. and Utrecht, The Netherlands, 2019. intensity greenhouses, energy used for heating dominates the consumption. For both crops covered in the low energy intensity greenhouses, the energy inputs are around 250 GJ/ha, whereas in high energy intensity greenhouses they are many times higher, ranging from around 7000 GJ/ha to 11,500 GJ/ha.

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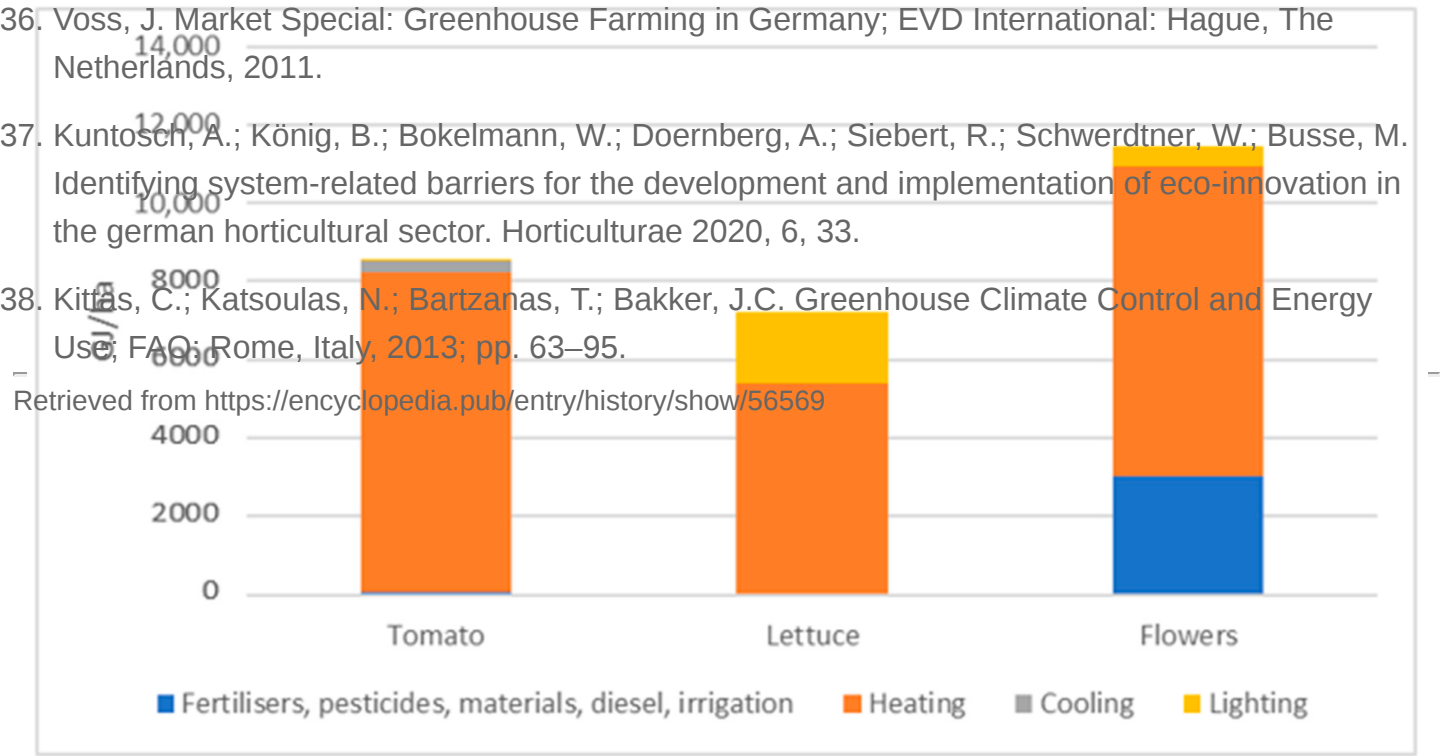


Figure 3. Energy consumption in high energy intensity greenhouse production in Greece (GJ/ha) (based on [26][27][28]).

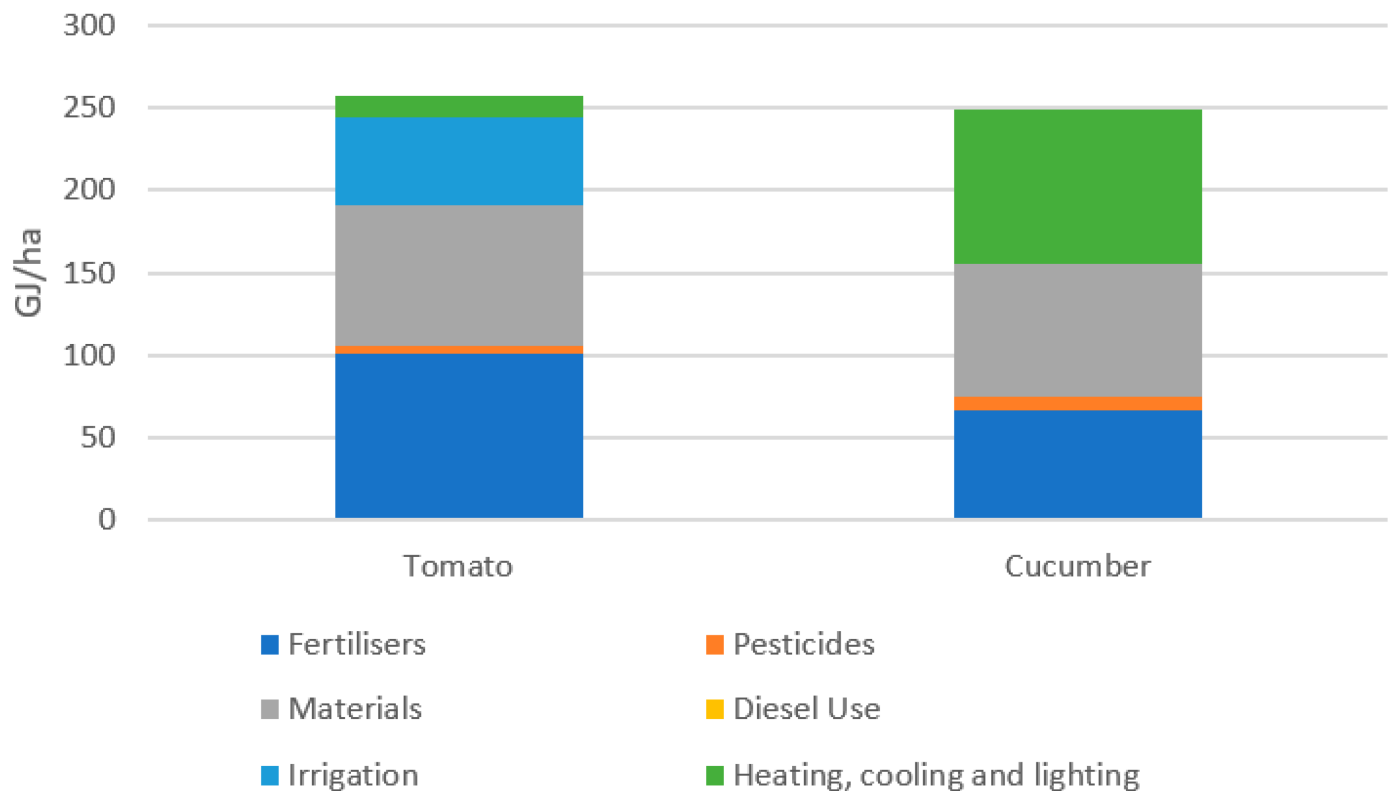


Figure 4. Energy consumption in low energy intensity greenhouse production in Greece (GJ/ha) (based on [15]).

3.4. Italy

The area under greenhouse cultivation in Italy is approximately 30,000 ha, with 6000 ha serving as permanent greenhouse structures [20]. The greenhouses in Italy are distributed all over the Italian peninsula with the majority, about 60%, located in southern regions. There are different types of greenhouses used, ranging from simple structures covered by plastic films to fully automated glass structures [29]. The former greenhouse type is predominant in southern regions due to favourable climatic conditions, which allow for the use of simple and inexpensive structures for winter cropping of warm season species, and are usually equipped with simple heating systems. On the other hand, greenhouses situated in the northern areas of Italy consist, mostly, of structures covered with glass. It is calculated that approximately 20–30% of the Italian greenhouses are equipped with heating and cooling systems [30]. Due to favourable growing conditions and reduced costs, greenhouse cultivation has been moving southward. The cultivation of pot plants occurs in glasshouses and is generally found in northern regions [29]. The Italian greenhouse sector is of considerable economic importance for the national agricultural systems and a significant energy consumer. Even though Italian greenhouse systems only represent around 0.032% of the EU UAA, Italian greenhouse crops account for a turnover of more than EUR 3 billion [31], and according to the Italian Ministry of Economy and Finance, heating for greenhouses powered by fuel accounts for 0.72 millions of tonnes of oil equivalent (Mtoe), which is equivalent to nearly 24% of the direct energy consumption in Italian agriculture, while electricity use in greenhouses accounts for only 0.02 Mtoe [20].

Data for Italy were only located for crops cultivated in low energy intensity greenhouses in central Italy (**Figure 5**). Within these data, energy use ranges between 60 GJ/ha to 140 GJ/ha and suggest that electricity accounts for around half of all energy inputs, followed by diesel at around a quarter of all energy inputs [\[32\]](#).

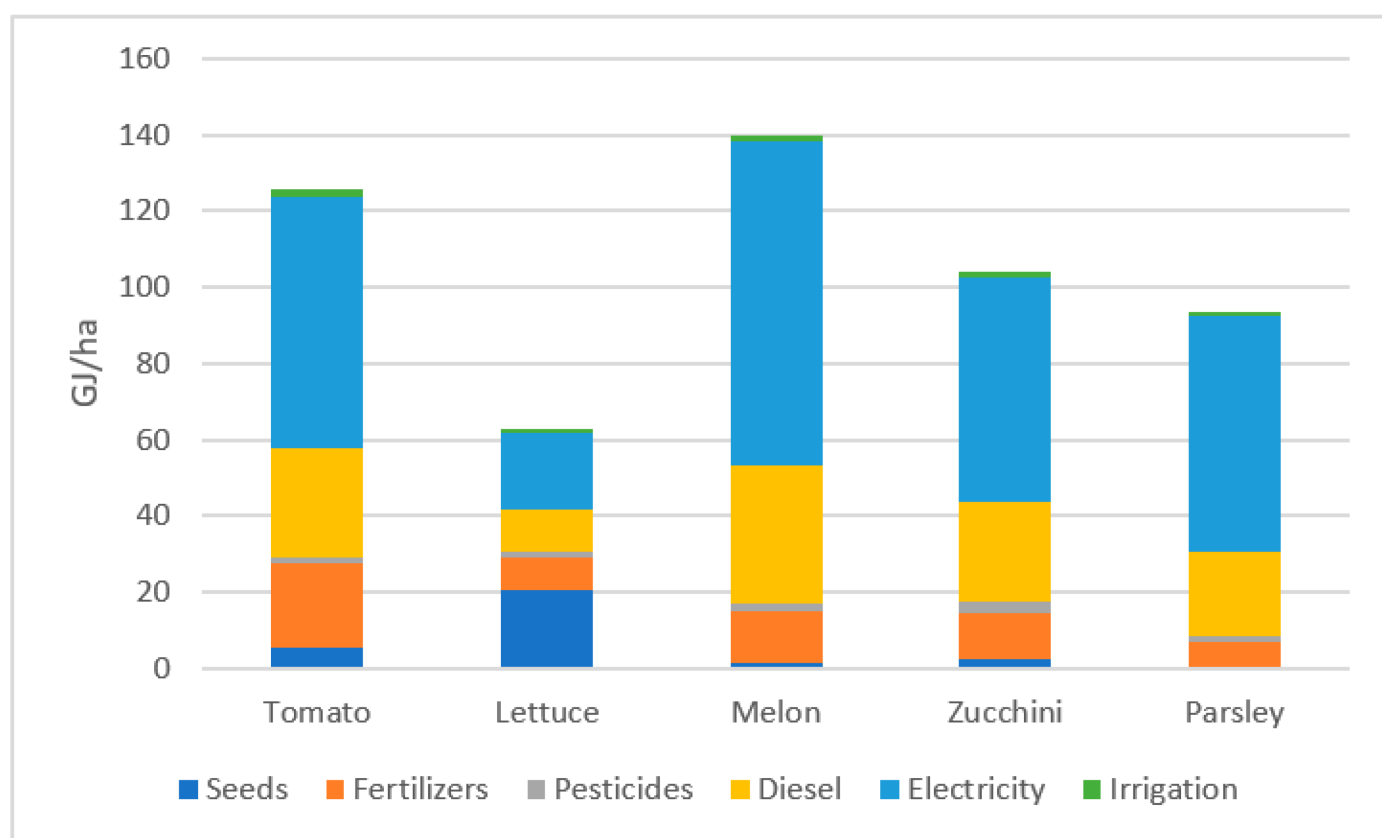


Figure 5. Energy consumption low-energy intensity greenhouse production in Italy (GJ/ha) (based on [\[32\]](#)).

3.5. The Netherlands

In the Netherlands, 9688 ha are covered by greenhouses; around 45% of this is devoted to vegetable production, 25% to flower production, and 15% to fruit production. Production is generally intensive and yields are high, especially as compared to greenhouse production in other countries, with average production per m² in 2019 at 50 kg for tomatoes and 68 kg for cucumbers [\[33\]](#). Due to this production intensity, The Netherlands produces 21% of the peppers, 20% of the cucumbers and 17% of the tomatoes grown in Europe [\[34\]](#). Dutch greenhouses are generally characterized by large permanent structures that are heavily climate controlled, with large scale heating, cooling, lighting, and ventilation facilities. In recent years, large transitions have occurred that have started to improve efficiency and dramatically cut the amounts of inputs used, such as water and pesticides.

According to the annual publication of the energy monitor of the Dutch greenhouse sector, the total current energy consumption in the Dutch greenhouse sector stands at 106.8 petajoules (PJ) [\[9\]](#). Most energy consumption is associated with heating, accounting for around 74% of the total energy inputs, and electricity at 26%. Overall, energy use is dominated by energy from natural gas (accounting for 99.9% of the total fossil sources). Around 58% of electricity was produced at the greenhouses by cogeneration, while 42% was purchased. In 2019, 10 PJ (9.4%)

of the energy consumed in the Dutch greenhouse sector came from renewable sources. Energy from renewable sources has been growing rapidly in recent years and increased by 35% between 2017 and 2018. In particular, sustainable (mainly geothermal) heat has been growing rapidly, a trend that is likely to continue ^[9].

On a per crop basis, for the studies that have detailed data, the vast majority of the total energy inputs are connected with heating, accounting for over 99% of energy use, while other inputs, such as fertilizers, are minor (**Figure 6**). It is important to note that these energy requirements are amongst the highest recorded for all greenhouses in the EU-27. The most important activities for greenhouses in the Netherlands are heating, ventilation and air circulation, cooling, humidification, irrigation, pesticides, CO₂ enrichment, and others ^{[9][35]}.

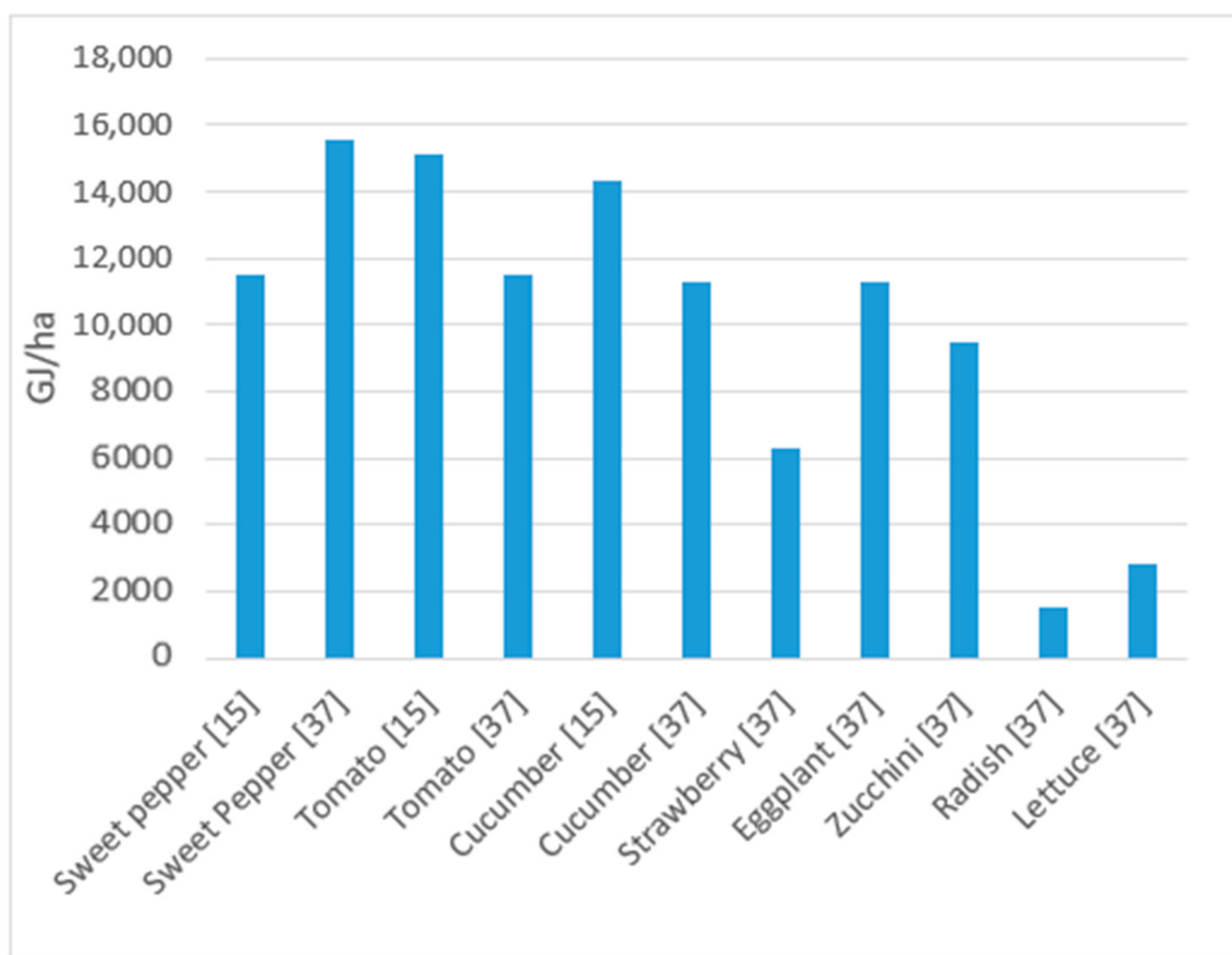


Figure 6. Greenhouse energy consumption for selected crops in the Netherlands (GJ/ha) (based on ^{[15][35]}).

3.6. Germany

Data on greenhouse production in Germany is relatively scarce. Voss (2011) suggest that only 3689 hectares are covered by greenhouses, of which an estimated 80% are glass greenhouses, 15% foil, and 5% stiff plastics, while 2500 hectares are heated ^[36]. The main crops cultivated in the German greenhouses are tomato, cucumber,

certain plants and other crops. It is important to note that most of the facilities are relatively old; 43.1% of the total number of greenhouses, which corresponds to almost 1600 ha, were built before 1982. Even though some of these facilities were upgraded to comply with the modern-day standards, most of them are still outdated and only 10.6% of the total facilities were built after 2000. Furthermore, most of the production area under glass which is specialized for vegetable crops is owned by “small” farmers. Regarding holding size, 3800 facilities are 1000 m², almost 5600 facilities cover between 1000 m² and 5000 m² and the remainder of facilities are larger than 5000 m² [36].

For Germany, Visser et al. (2012) investigates the energy consumption in greenhouses for tomato and cucumber production. The biggest share of the energy inputs is attributed to heating purposes, whereas a small portion of the energy inputs account for fertilizers (**Figure 7**). The available data suggest that close to 13,000 GJ/ha are consumed in the greenhouse cultivation of both crops, of which 99.6% accounts for heating purposes. According to Kuntosch et al. (2020), black coal is the largest source of energy for heating purposes followed by natural gas and renewables (**Figure 8**) [37].

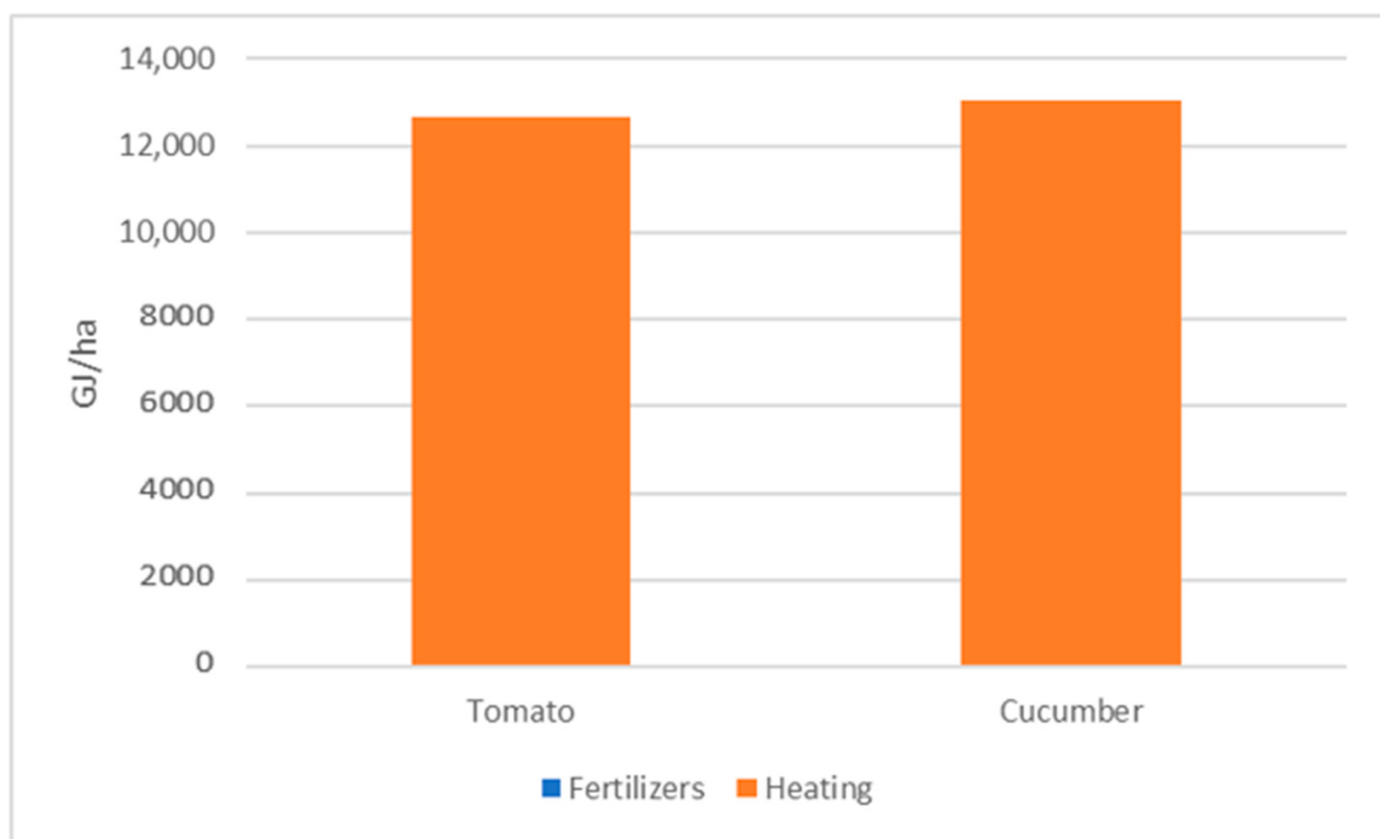


Figure 7. Energy consumption in the German greenhouse sector (GJ/ha) (based on [15]).

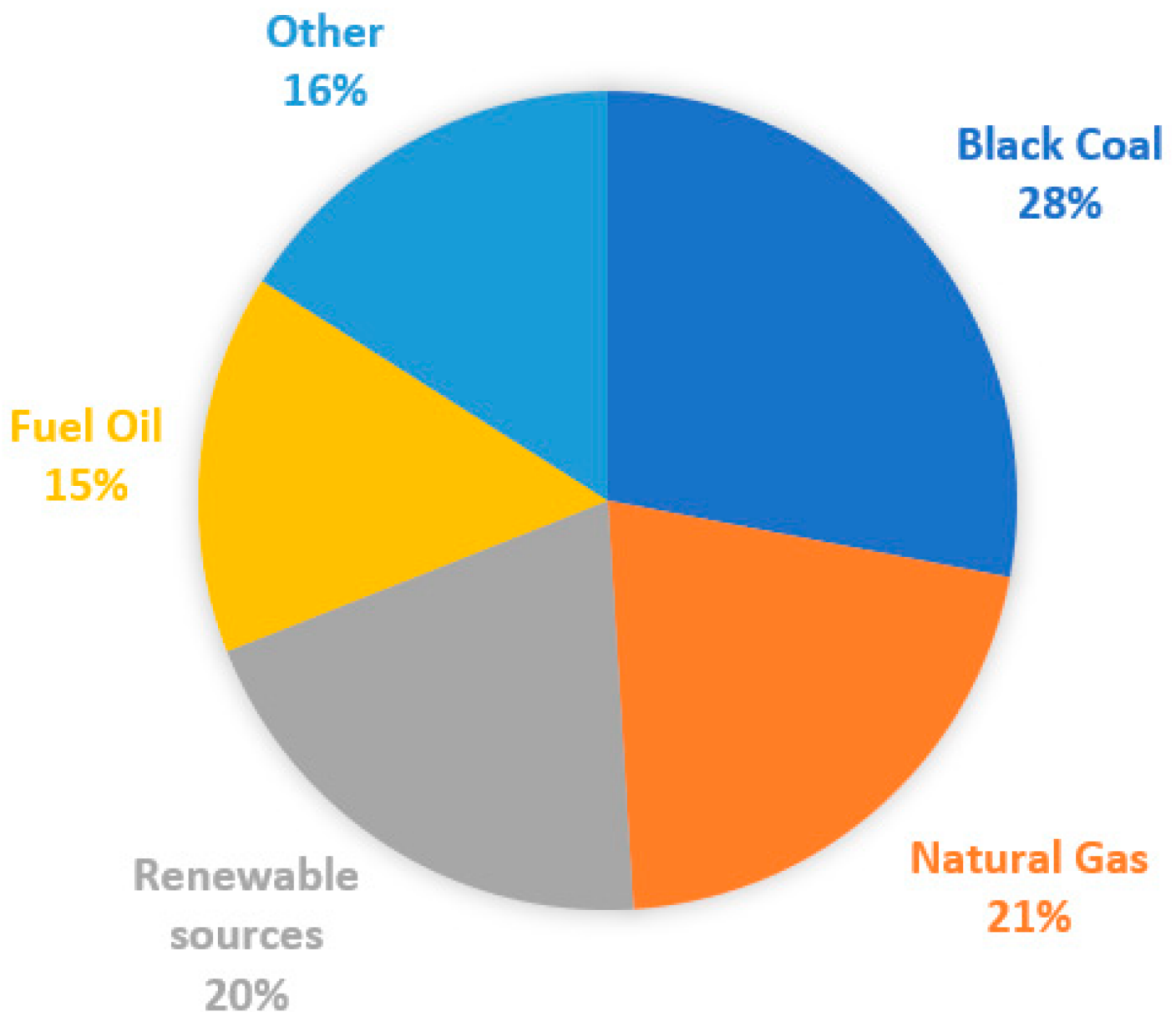


Figure 8. Percentages of the energy sources used for greenhouse heating in Germany (based on [\[37\]](#)).

3.7. Tomatoes

Figure 9 and **Figure 10** provide an overview of the energy data of high and low energy intensity greenhouse tomato production. They are presented according to country and in cases where multiple data points are available for one country simple averages were calculated. These data show some variations within categories, with energy inputs for high energy systems ranging from around 8000 GJ/ha in Greece to around 15,000 GJ/ha in the Netherlands. In the high energy intensity systems, the vast majority of energy inputs are associated with heating and cooling activities, while in the low energy intensity systems fertilizers are the largest energy inputs. Importantly, this illustrates that energy inputs in high energy intensive tomato production systems are around 50 times greater per hectare than in low energy intensive systems. This energy intensity translates into large differences in final

yield, for instance, in the Netherlands the average tomato yield is around 50 kg/m² while in southern Italy it is 7.6 kg/m² [18].

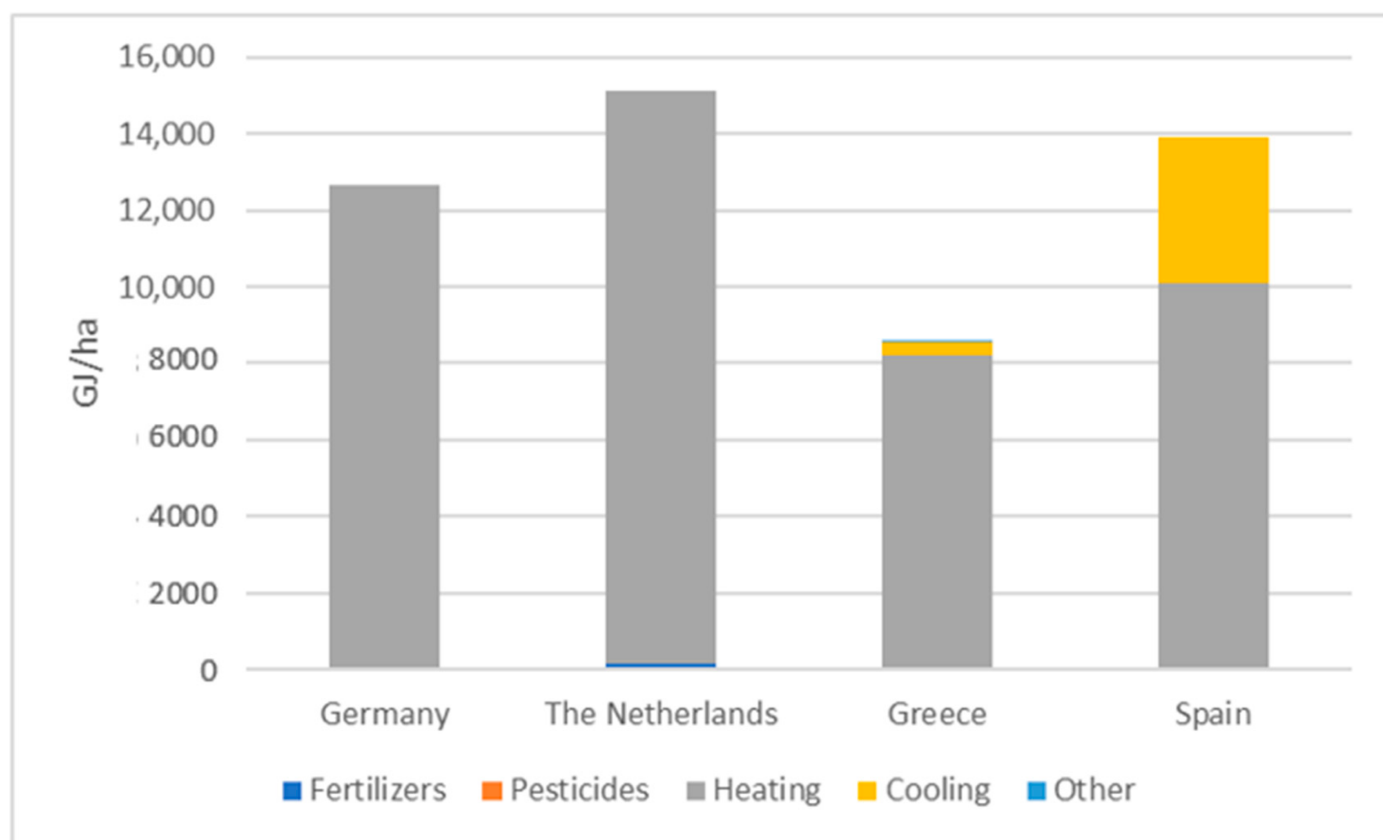


Figure 9. Energy inputs in high energy intensity tomato production systems (GJ/ha) (based on [15][23][38]).

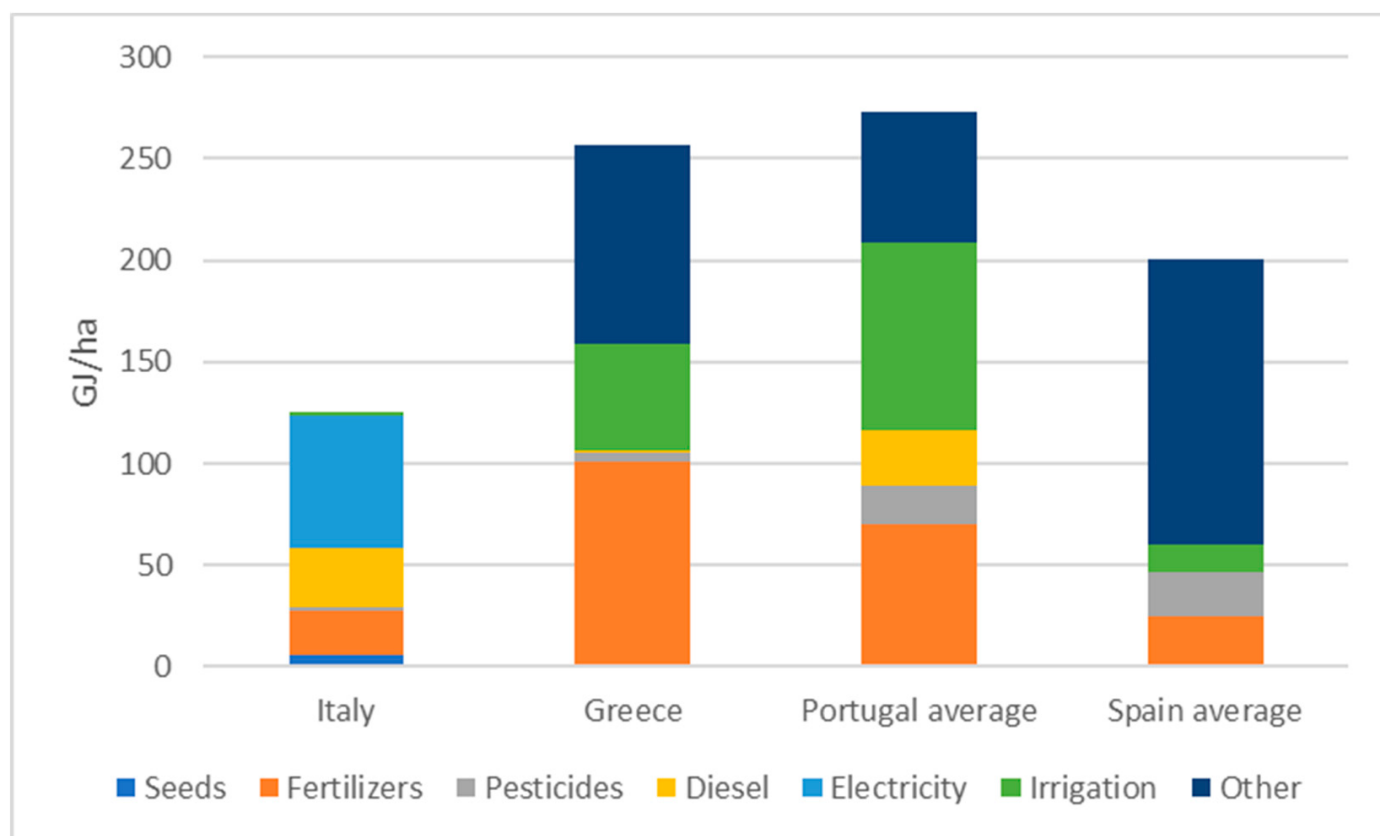


Figure 10. Energy inputs in low energy intensity tomato production systems (GJ/ha) (based on [\[15\]](#)[\[24\]](#)[\[32\]](#)).