TE TARI TIAKI PŪNGAO
ENERGY EFFICIENCY & CONSERVATION AUTHORITY

Energy benchmarking in the covered crops industry

Produced for Tomatoes NZ, Vegetables NZ and EECA.

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CONTENTS

[1] Intro & summary

The aim of this study is:
To create a benchmark for energy use in the global covered crop industry.

(a) Define average energy use per m^2 and energy intensity per yield output over differing crop types demonstrated in the Netherlands

(b) High-level review of how energy intensity in Netherlands covered crops has changed with improved energy efficiency

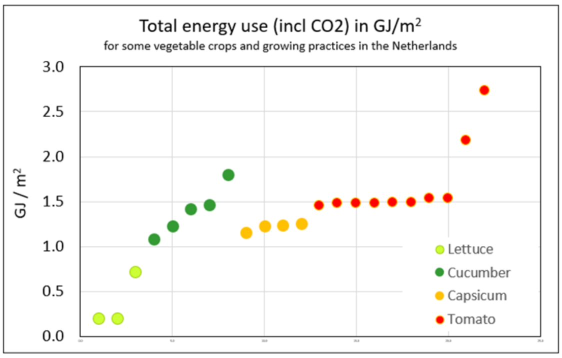
(Helen Barnes, Tomatoes NZ)

Two sources of information were used:

- 'Quantitative Information for the Glasshouse Industry 2019' (in Dutch) for (a).
- 'Energy monitor of the Dutch glasshouse industry 2020' (in Dutch) for (b)

In summary

Measured over the entire glasshouse industry in the Netherlands (over 10,000 hectares) the average on-farm energy use is typically **1.1 - 1.2 GigaJoule/m²/year**, **or 306-334 kWh/m²/y.** It has been stable at this range since 2006, after gradually coming down from 1.6 GJ/m² in 1996. However, there are huge differences between cultivations. The findings are summarized here:



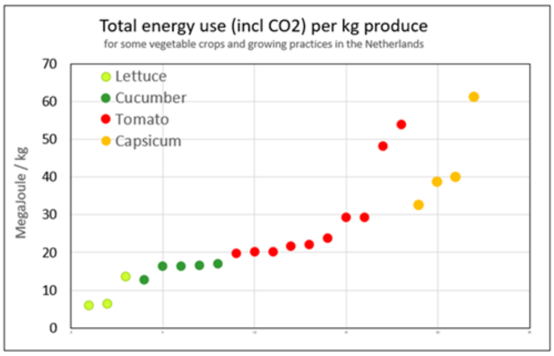


Figure 1. Summary of the results: left: energy use in GJ/m². Right: energy intensity in MJ/kg.

Energy use m² depends strongly on the growing practices and varies from **0.2 to 2.73 GJ/m²**. By far the lowest is lettuce as that needs little heating (**0.2 GJ/m² or 55 kWh/m²**). It is extremely high for year-round tomato cultivation with high-level lighting with High Pressure Sodium lamps (**2.73 GJ/m² or 761 kWh/m²**).

Energy input per kg also has a wide range: **6 to 60 MJ/kg**. Lettuce is again the lowest due to low heat requirement (6.2 MJ/kg or 1.7 kWh/kg). Cucumber requires a warm climate, but has a very high yield and therefore a low energy intensity per kg (12-17 MJ/kg). All tomatoes require a warm climate, but the small types (cocktail and cherry) have a low yield. Therefore the energy per kg is high (48 MJ/kg or 13.4 kWh/kg). At the top is point capsicum, which not only needs a lot of energy but also has a low yield. Its energy intensity is **61 MJ/kg or 17 kWh/kg**.

[2] Background

The Dutch glasshouse industry

The Dutch glasshouse industry currently covers **10,078 hectares**, and includes a wide range of crops (vegetables, flowers, pot plants, nursery). A large percentage of the hectares are advanced to very advanced glasshouses. Typically, the industry is made up of several huge state-of-the-art glasshouse complexes, plus numerous medium-size semi-advanced to advanced glasshouses, and many small older glasshouses. There is continuous rebuild going on.

Total energy use on **10,078 ha** was **110 PetaJoule,** and **CO2 emission was 6.1 Megaton** in 2020.

The average on-farm energy use was **1.1 GJ/m^2/y** and average **CO2 emission was 45.7 kg/m^2/y.** Intensive programmes and policies are in place to stimulate a reduction in energy use and transition to sustainable / renewable energy sources. The programmes have been successful at times but are not achieving the current targets. (Source: Energiemonitor 2020).

The predominant energy source in the Netherlands was* natural gas, mined in the Netherlands. The Dutch government declared in 2019 that gas mining and gas usage would be phased out by 2030, but given the current uncertainty in Europe, this is being reconsidered. Other energy sources (other than natural gas) were gradually adopted from about 2010 onwards, such as geothermal energy, biofuels, and low-grade heat combined with heatpumps.

(*) due to uncertainty at the moment, it is written in the past tense

Data conversion

Original data on natural gas are often in m^3 and electricity data are in kiloWatthour. For comparison, we convert all data to **MegaJoule or GigaJoule**. We used the gross calorific values of Dutch (Groningen) natural gas, which is: 1 m^3 gas equals 35.1 MJ, or 1 m^3 gas equals 9.8 kWh. The other conversion is that 1 MJ equals 0.278 kWh, or 1 GJ equals 278 kWh. Vice-versa 1 kWh equals 3.6 MJ.

Influence of the CHP on energy consumption

From 2005 onwards, many medium and large-scale glasshouse complexes (e.g. over 5 ha) in the Netherlands installed a CHP (combined heat and power engine, or co-generator). It burns natural gas and produces heat, electricity and CO2. The electricity produced can be:

a) used on-farm for lighting, initially with HPS lamps, later with LEDs, and/or
b) used on-farm for standard greenhouse operations (roughly 10 kWh/m2/y), and/or
c) sold to a third party or the grid ('export')

Selling electricity became a lucrative income stream for many Dutch greenhouse operators from 2005 onwards. Therefore more growers installed a CHP: in 2017, two-third of the greenhouse area was heated by a CHP.

Collectively these CHP's 'exported' 9 billion kWh electricity per year, which counted for 8% of the national electricity need of the Netherlands (source: 'Energiemonitor 2018'). The attractive income from selling power led to an increase in the natural gas consumption in greenhouses with a CHP. Figure 2 shows data related to CHP use, collected over the entire glasshouse industry, calculated back to GJ per m^2.

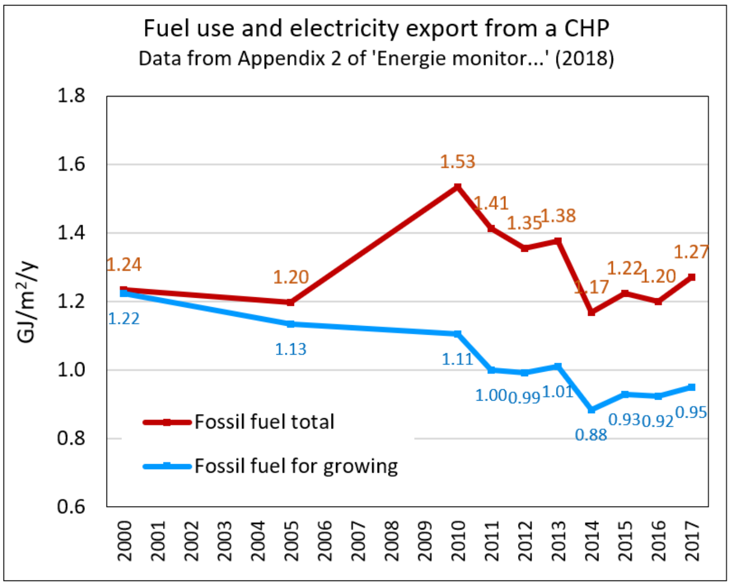


Figure 2. Natural gas intake (red line) by CHP's in the Dutch glasshouse industry, and energy used for growing (blue line). Numbers are for the entire industry, calculated back to GJ per m^2.

The red line shows the amount of natural gas burned in the CHP, while the blue line is the amount of energy actually used for growing. The difference was electricity 'export' (sale to a third party). The 'extra' natural gas consumption for electricity production amounted to 30-40% of the energy input in the years 2010-2017. The exported electricity is deducted from the energy use for greenhouse climate control. A similar complication arises later, when heat is captured in glasshouses and exported to third parties. See page 7.

[3] High-level review how energy intensity has changed in the Netherlands

The average energy intensity of glasshouses in the Netherlands over the last 20 years and over the whole industry is shown in Figure 3. Over the period 2006-2020, the energy use (green line) was mostly **1.1 - 1.2 GJ/m²/y, or 306 - 334 kWh/m²/y**. These figures are averages over all crops (vegetables, flowers, pot plants, nursery) and over all types of greenhouses, which is for 99% glasshouses.

1990 – 2000 (not in the graph). The natural gas consumption was high in the early 1990's, and had a sharp peak in 1996. Average energy use was 45 m³/m²/y natural gas, or **1.6 GJ/m²/y**. Some crops were grown colder or not in the winter season and used far less energy, while other crops could use over 60 m³/m²/y. There was a steep drop in energy use in 1997, and the decline continued gradually, driven by cost saving and growing environmental awareness. Older greenhouses were steadily replaced by new modern types.

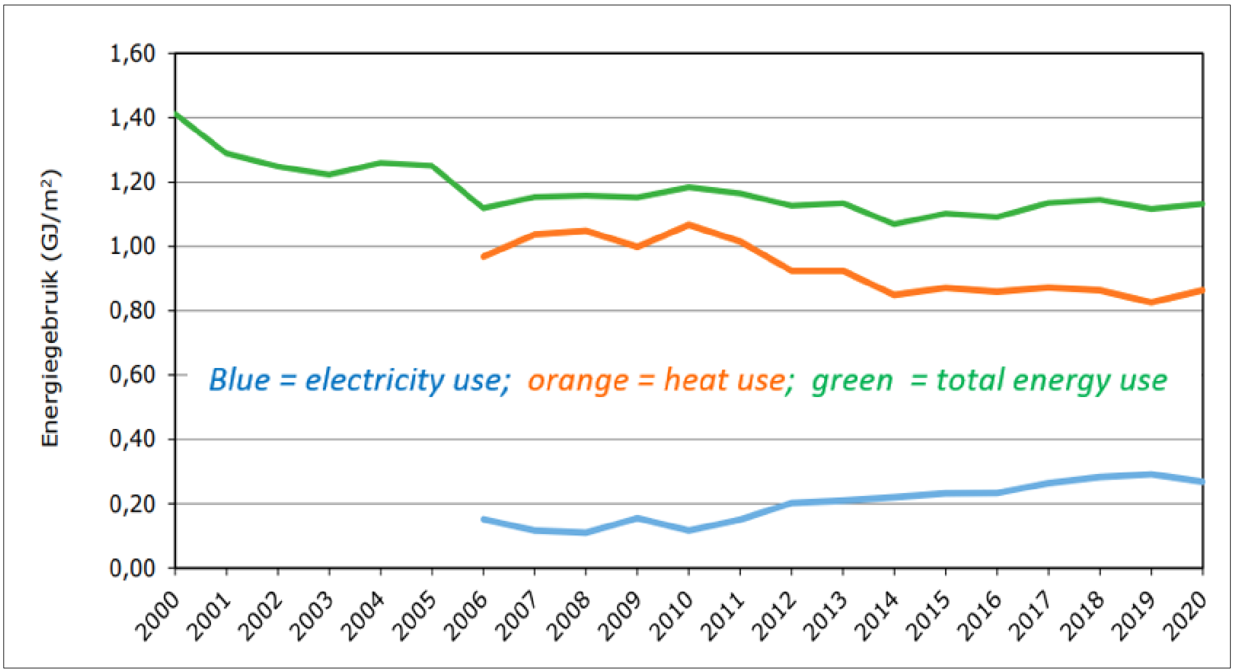


Figure 3. Energy use in the glasshouse industry in the Netherlands (GJ/m²/y) in 2000-2020, corrected for outside temperature. Source: Energiemonitor 2020.

2000 - 2006. The trend in energy use was downwards, thanks to the implementation of energy saving technologies such as improved boiler control, flue gas condenser, insulation of boiler and heat transport pipes, improved heating network, heat storage buffer, fixed plastic screens, moveable thermal screens, wall screen, better sensors, more science, and high-tech climate control computers.

2006 - 2010: After a significant drop in 2006, **the use of natural gas slowly increased** due to the adoption of **natural gas fuelled CHP's**. As discussed earlier (see Figure 2), many large to medium-scale growers invested in a CHP, and then entered the electricity production market.

2010 - 2014: the total fossil fuel consumption declined markedly. Also the line for 'fossil fuel for growing' in Figure 2 declined significantly. **In 2014, energy use was around 1.06 GJ/m2/y**. A wide range of newer energy saving measures was (being) adopted, e.g. improved climate control practices including 'The New Way of Growing' and 'Growing by Plant Empowerment'. Improvements included better humidity control, use of screens, even double screens, building semi-closed greenhouses, use of mechanical ventilation, use of reject or waste heat, harvesting heat from the glasshouse, 'heat and cold storage' in the aquifer, and transition to other fuels. The first projects with geothermal energy started around 2010, where geothermal energy replaced natural gas.

2015 - 2018: the total energy use was slightly increasing, despite further adoption of the energy-saving measures mentioned above. For instance, in 2017 there were 55 geothermal projects, covering 621 ha of glasshouses, which was 7% of the total glasshouse area.
In 2017 the average energy use was **1.15 GJ/m2/y.** The increase was partly due to growers with a CHP shifting from selling electricity to using electricity. This led to **'intensification'** of the cultivation involving increased lighting (installing lighting for the first time, and opting for a <u>higher</u> light intensity). Also CO2 enrichment increased as many CHP's got fitted with a flue gas purification installation. The 2017 energy use in GJ per m^2 was on par with energy use a decade earlier (2007-2010), which was a disappointing outcome. In various crops the energy efficiency (production per unit energy) had increased. But the current goal is reduction in CO2 emission, and thus in energy use, in absolute terms, rather than relative to the production.

2019 - 2020: energy consumption over the whole industry and per m^2 has increased (Figure 3). Also the energy efficiency deteriorated (not shown). Again a disappointing outcome.

The 2020 version of the Dutch 'Energiemonitor' is reporting increasingly in units of CO2 emission rather than energy units. See Figure 4 on the next page. Of course we can convert from kg CO2 to MJ energy (see Table below), but this requires assumption on the fuels involved.

Table 1. CO2 emission per unit energy for some fuels. Similar tables can be used to convert data from energy to CO2 and vice-versa Source: New Zealand Energy Information Handbook, 2008.

Table 4.3: Typical energy data for LPG and component gases.
(Source: NZS 5435, 1996 "Specifications for Liquefied Petroleum Gas")

		CO_2 emission factor	
Product	C content (% mass)	tCO_2/TJ	tC/TJ
Propane	82.0	59.6	16.3
Butane	83.0	61.4	16.8
LPG	82.4	60.4	16.5

Table 4.4: Typical values of CO_2 emission factors for LPG and component gases

Fuel / Fuel type	GCV	C content	CO_2 emission factor	
	TJ/kt	% mass	tCO_2/TJ	tC/TJ
Gasoline Fuels				
Premium petrol	47.2	86.0	67.0	18.3
Regular petrol	47.2	86.0	66.2	18.1

So recent reporting of the Dutch glasshouse industry is more on CO_2 emission than energy use. The CO_2 emission has dropped a lot over 20 years, but it appears to creep up now. Moreover, the current total emission is 6.1 Mton, which is above the current target of 4.6 Mton. Also the emission on kg CO_2 per m^2 seems to increase (green line).

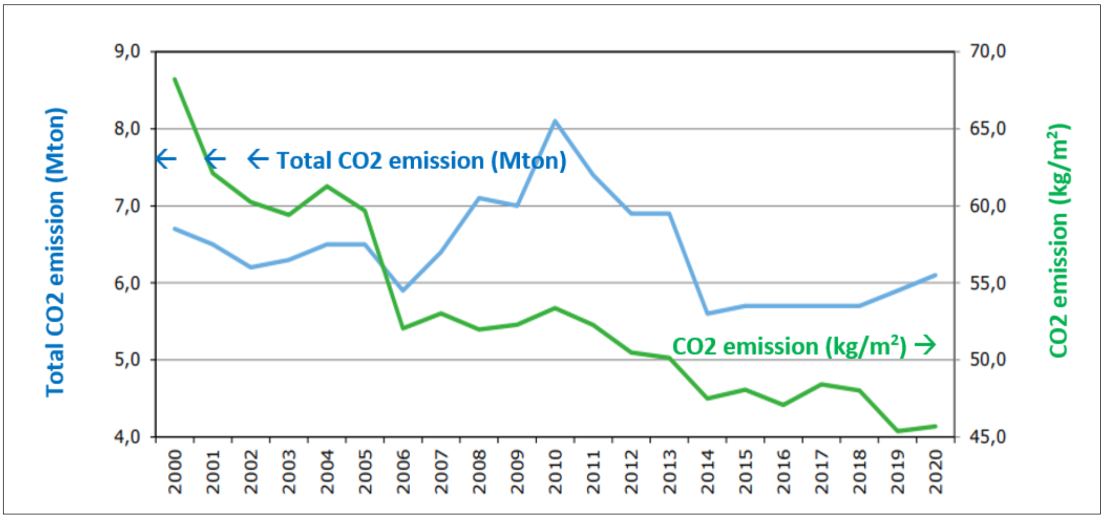


Figure 4. CO_2 emission by the glasshouse industry in the Netherlands in Megaton (blue line) and in kg/m^2/y green line) in 2000-2020. Source: Energiemonitor 2020.

The 'Energiemonitor 2020' claims that the increase in total CO_2 emission in the last two years were caused by:

- increase in hectares
- increase in sale of electricity from CHP's (presumably the heat and/or CO_2 are used)
- decrease in the purchase of non-sustainable heat from third parties
- increase in energy use per m^2

This was counterbalanced only partly by:

- increased use of sustainable energy
- increased purchase of (sustainable) electricity

The average CO_2 emission per m^2 is now 45.7 kg/m^2/year.

Data on energy use are becoming more complex, as electricity and heat are purchased, and also produced and sold. See Table below.

Table 2. Factors that are part of the equation to determine the CO_2 emission of the Dutch glasshouse industry. Source: Energiemonitor 2020.

Factor	eenheid	2010	2014	2018	2019	2020 v)
Area	ha	10.307	9.488	8.990	9.688	10.078
Sale of electricity	TWh	8,2	5,2	5,4	5,8	6,1
Use of sustainable energy	PJ	2,4	4,0	6,7	10,0	11,5
Purchase electricity (non-sust.)	TWh	2,0	2,1	2,5	2,9	3,1
Purchase heat (non-sustainable)	PJ	5,3	3,4	3,4	2,8	2,2

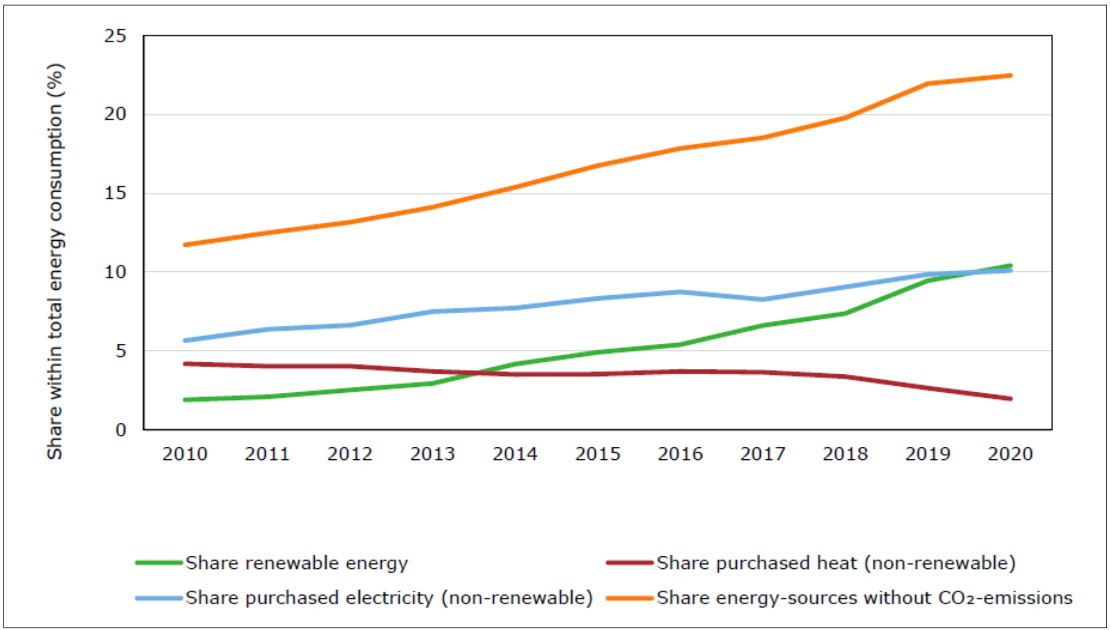


Figure 5. Use of various energy sources as percentage of total energy use. The orange line is the summation of the three other lines.

[4] Energy intensity per m² and per kg for four main crops

The following two tables give an overview of various crops and growing techniques.
In Table 3 the crops are ranked according to energy used for growing (GJ/m²).
In Table 4 the same crops are ranked according to energy per kg product (MJ/kg).

Table 3. Energy use in Dutch greenhouses for growing four vegetable crops with some variations in crop type and growing technique, ranked by total energy use (including CO2) in GigaJoule per m² growing area. (Data: KWIN, 2019).

		Table no	duration of greenhouse use	CHP run time	insulation value screen(s)	production (weight)	gas for climate control (3)	electricity climate control (2)	CO2 purchased (3)	***total energy incl. CO2 (2)***	**total energy incl. CO2 per kg (2)**
			weeks	hours/year	%	kg/m²	GJ/m²	GJ/m²	GJ/m²	***GJ/m²***	**MJ/kg**
Caps	Caps, green, 2 screens, 48 wks	G21	48	2735	40 + 35	35.6	1.42	-0.50	0.24	***1.16***	**32.48**
Caps	Caps, red/orange 2 screens, 50 wks	G24 -26	50	2903	40 + 35	30.9	1.51	-0.52	0.24	***1.23***	**39.80**
Caps	Caps, yellow, 2 screens, 50 wks	G20	50	2904	40 + 35	32.1	1.52	-0.52	0.24	***1.24***	**38.64**
Caps	Caps, red pointed, 2 screens, 51 wks	G27	51	2987	40 + 35	20.7	1.56	-0.54	0.24	***1.26***	**60.92**
Cuc	Cuc, high wire, 2 screens, 42 wks	G12	23+21	2449	40 + 20	85	1.37	-0.45	0.16	***1.09***	**12.78**
Cuc	Cuc, just plastic film, 47 wks	G15	21+11+15	2828	40+35F	74	1.60	-0.51	0.14	***1.23***	**16.56**
Cuc	Cuc, 2 screens, 50 wks	G14	22+10+18	2880	40 + 20	87	1.70	-0.45	0.16	***1.42***	**16.38**
Cuc	Cuc, 1 screen + plastic film, 50 wks	G13	22+10+18	3016	40+35F	85	1.75	-0.45	0.16	***1.46***	**17.12**
Cuc	Cuc, 2 screens, 47 wks, LIGHTING	G16	21+11+15	4285	40 + 20	109	2.08	-0.45	0.16	***1.80***	**16.48**
Lett	Lettuce, 220gram, 52 weeks	G17	52	xx	xx	31.7	0.20	0.00	0.00	***0.20***	**6.2**
Lett	Lettuce, 400gram, 52 weeks	G18	52	xx	xx	32.8	0.20	0.00	0.00	***0.20***	**6.0**
Lett	Lettuce, on water, 220g, LIGHTING (low)	G19	52	xx	xx	53.2	0.17	0.22	0.33	***0.71***	**13.4**
Tom	Tom, truss, heavy, 1 screen, 50 wks, buy CO2	G35	50	xx	40	73.4	1.21	0.00	0.25	***1.46***	**19.84**
Tom	Tom, truss heavy, 1 screen, 50 wks fluegas CO2	G36	50	xx	40	73.4	1.48	0.00	0.00	***1.48***	**20.19**
Tom	Tom, cherry loose, 1 screen, 50 wks	G30	50	2919	40	30.7	1.80	-0.53	0.21	***1.48***	**48.25**
Tom	Tom, beef, 1 screen, 50 wks,	G39	50	2919	40	68.3	1.80	-0.53	0.21	***1.48***	**21.69**
Tom	Tom, round, 1 screen, 50 wks	G32	50	2919	40	67.4	1.80	-0.53	0.21	***1.48***	**22.03**
Tom	Tom, truss, heavy, 1 screen, 50 wks	G34	50	2919	40	73.4	1.80	-0.53	0.21	***1.48***	**20.23**
Tom	Tom, truss, fine, 1 screen, 51 wks	G33	51	3003	40	52.6	1.87	-0.54	0.21	***1.54***	**29.23**
Tom	Tom, truss med., 1 screen, 51 weeks	G38	51	3003	40	64.4	1.87	-0.54	0.21	***1.54***	**23.87**
Tom	Tom, cocktail truss, 1 screen, 50 wks, LIGHTING	G31	50	3517	40	40.4	1.73	0.23	0.22	***2.18***	**53.94**
Tom	Tom, truss, heavy, 1 screen, 50 wks, LIGHTING	G37	50	3825	40	93.3	1.86	0.64	0.23	***2.73***	**29.30**

Table 4. Energy use in Dutch greenhouses for growing four crops, with some variations in growing techniques, ranked by total energy (including CO2) in MegaJoule per kg product. (Data source: KWIN, 2019).

		Table no	duration of culti-vaiton	CHP run time	insulation value screen(s)	production (weight)	gas for climate control (3)	electricity climate control (2)	CO2 purchased (3)	**total energy incl. CO2 (2)**	***total energy incl. CO2 per kg***
			weeks	hours per year	%	kg/m^2	GJ/m^2	GJ/m^2	GJ/m^2	**GJ/m^2**	***MJ/kg***
Lett	Lettuce, 400gram, 52 weeks	G18	52	xx	xx	32.8	0.20	0.00	0.000	**0.20**	***6.0***
Lett	Lettuce, 220gram, 52 weeks	G17	52	xx	xx	31.7	0.20	0.00	0.000	**0.20**	***6.2***
Lett	Lettuce, on water, 220g, LIGHTING	G19	52	xx	xx	53.2	0.17	0.22	0.33	**0.71**	***13.4***
Cuc	Cuc, high wire, 2 screens, 42 wks	G12	23+21	2449	40 + 20	85	1.37	-0.45	0.16	**1.09**	***12.78***
Cuc	Cuc, 2 screens, 50 wks	G14	2+10+18	2880	40 + 20	87	1.70	-0.45	0.16	**1.42**	***16.38***
Cuc	Cuc, 2 screens, 47 wks, LIGHTING (low)	G16	1+11+15	4285	40 + 20	109	2.08	-0.45	0.16	**1.80**	***16.48***
Cuc	Cuc, just plastic film, 47 wks	G15	1+11+15	2828	40+35F	74	1.60	-0.51	0.14	**1.23**	***16.56***
Cuc	Cuc, 1 screen + plastic film, 50 wks	G13	2+10+18	3016	40+35F	85	1.75	-0.45	0.16	**1.46**	***17.12***
Tom	Tom, truss, heavy, 1 screen, 50 wks, buy CO2	G35	50	xx	40	73.4	1.21	0.00	0.25	**1.46**	***19.84***
Tom	Tom, truss heavy, 1 screen, 50 wks fluegas CO2	G36	50	xx	40	73.4	1.48	0.00	0.00	**1.48**	***20.19***
Tom	Tom, truss, heavy, 1 screen, 50 wks	G34	50	2919	40	73.4	1.80	-0.53	0.21	**1.48**	***20.23***
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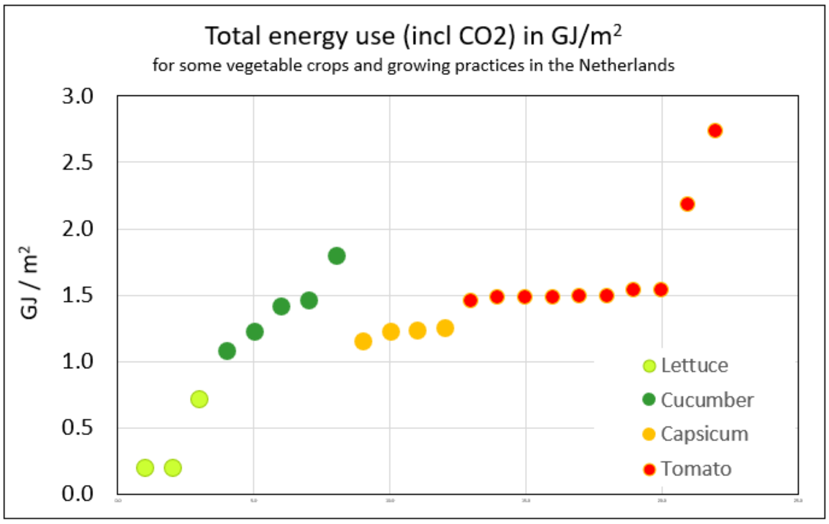
Tom	Tom, truss, heavy, 1 screen, 50 wks, LIGHTING	G37	50	3825	40	93.3	1.86	0.64	0.23	**2.73**	***29.30***
Tom	Tom, cherry loose, 1 screen, 50 wks	G30	50	2919	40	30.7	1.80	-0.53	0.21	**1.48**	***48.25***
Tom	Tom, cocktail truss, 1 screen, 50 wks, LIGHTING	G31	50	3517	40	40.4	1.73	0.23	0.22	**2.18**	***53.94***
Caps	Caps, green, 2 screens, 48 wks	G21	48	2735	40 + 35	35.6	1.42	-0.50	0.24	**1.16**	***32.48***
Caps	Caps, yellow, 2 screens, 50 wks	G20	50	2904	40 + 35	32.1	1.52	-0.52	0.24	**1.24**	***38.64***
Caps	Caps, red/orange 2 screens, 50 wks	G24 -2(	50	2903	40 + 35	30.9	1.51	-0.52	0.24	**1.23**	***39.80***
Caps	Caps, red pointed, 2 screens, 51 wks	G27	51	2987	40 + 35	20.7	1.56	-0.54	0.24	**1.26**	***60.92***



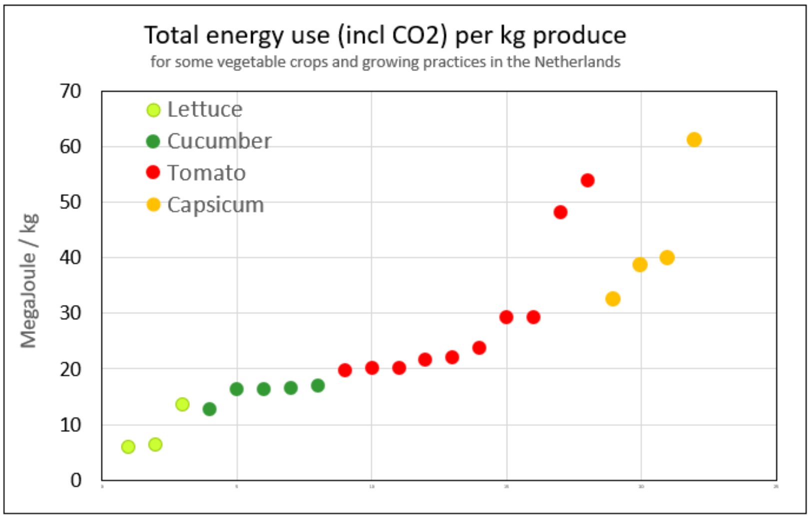


Figure 6 a & b. Graphic presentation of results from Table 3 & 4. Data Source: KWIN 2019.

Figure 6a shows the energy use per m². It depends strongly on the cultivation method. Energy use was by far the highest for two year-round tomato cultivations with high-level lighting with High Pressure Sodium lamps. The highest user used **2.73 GJ/m² or 760 kWh/m²**. The least energy intense was lettuce, with **0.2 GJ/m² or 55.6 kWh/m²**, as it requires little heating.

Figure 6b shows energy use per kg. That was lowest for crops with a low heat demand such as lettuce, and it is also low for crops with a high production, such as cucumber. Vice-versa, it is high for crops with a low production such as cocktail and cherry tomatoes and capsicums, especially point capsicums. Lettuce used **6 MJ/kg or 1.73 kWh/kg,** while point capsicum used **61 MJ/kg or 17 kWh/kg.**

The tables below and on the following pages provide a breakdown of the energy use.

Table 5a. Details of energy use for growing capsicum and lettuce in a glasshouse in the Netherlands with some variations in growing techniques. (Data source: KWIN, 2019).

		Capsicum				**Lettuce**		
		Caps, yellow, 2 screens, 50 wks	Caps, green, 2 screens, 48 wks	Caps, red/orange 2 screens, 50 wks	Caps, red pointed, 2 screens, 51 wks	Lettuce, 220gram, 52 weeks	Lettuce, 400gram, 52 weeks	Lettuce, on water, 220g, **LIGHTING** (low)
table nr -->		G20	G21	G24 -26	G27	G17	G18	G19
duration of greenhouse use	weeks	50	48	50	51	52	52	52
target heating temperature	°C	19	19	19	19	8	8	10
maximum Relative Humidity	%	88	88	88	88	92	92	92
CHP (cogeneration)	W/m² (elc)	50	50	50	50	xx	xx	xx
CHP run time	**hours/year**	**2904**	**2735**	**2903**	2987	**xx**	**xx**	**xx**
insulation value screen(s)	%	40 + 35	40 + 35	40 + 35	40 + 35	xx	xx	xx
lighting (intensity; duration)	W/m²; h/y	xx	xx	xx	xx	xx	xx	**30; 2000**
CO2 injection rate (own; purchased)	kg/ha/h	200; 75	200; 75	200; 75	200; 75	0; 0	0; 0	**80; 80**
production (pieces)	pieces/m²	xx	xx	xx	xx	144	82	241.8
production (weight)	**kg/m²**	**32.1**	**35.6**	**30.9**	**20.7**	**31.7**	**32.8**	**53.2**
profit estimate	Euro/m²	31	32	31	33	27	24	67
natural gas for cogenerator	m³/m²	39.3	37	39.3	40.4	0	0	0
natural gas for boiler	m³/m²	4	3.2	3.7	3.9	5.6	5.6	4.7
gas for climate control (1)	m³/m²	43.3	40.2	43	44.3	5.6	5.6	4.7
gas for climate control (2)	kWh/m²	424	394	421	434	55	55	46
gas for climate control (3)	GJ/m²	1.52	1.42	1.51	1.56	0.20	0.20	0.17
electricity purchased	kWh/m²	10	9	10	10	4	4	73
electricity sold	kWh/m²	-145	-137	-145	-149	0	0	0
electricity - other on-farm	kWh/m²	-10	-10	-10	-10	-4	-4	-12
electricity climate control (1)	kWh/m²	-145	-138	-145	-149	0	0	61
electricity climate control (2)	GJ/m²	-0.52	-0.50	-0.52	-0.54	0.00	0.00	0.22
CO2 purchased (1)	kg/m²	13.5	13.5	13.5	13.5	0	0	18.7
CO2 purchased (2)	kWh/m²	66	66	66	66	0.0	0.0	92
CO2 purchased (3)	GJ/m²	0.24	0.24	0.24	0.24	0.000	0.000	0.33
total energy excl. CO2 (1)	kWh/m²	279	256	276	285	55	55	107
total energy excl. CO2 (2)	GJ/m²	1.00	0.92	0.99	1.02	0.20	0.20	0.39
total energy incl. CO2 (1)	**kWh/m²**	**345**	**322**	**343**	**351**	**55**	**55**	**199**
total energy incl. CO2 (2)	**GJ/m²**	**1.24**	**1.16**	**1.23**	**1.26**	**0.20**	**0.20**	**0.71**
total energy incl. CO2 per kg (1)	**kWh/kg**	**10.76**	**9.05**	**11.09**	**16.97**	**1.73**	**1.67**	**3.74**
total energy incl. CO2 per kg (2)	**MJ/kg**	**38.64**	**32.48**	**39.80**	**60.92**	**6.2**	**6.0**	**13.4**

Table 5b. Details of energy use for growing cucumbers in a glasshouse in the Netherlands with some variations in growing techniques. (Data source: KWIN, 2019).

		Cucumber				
		Cuc, high wire, 2 screens, 42 wks	Cuc, 1 screen + plastic film, 50 wks	Cuc, 2 screens, 50 wks	Cuc, just plastic film, 47 wks	Cuc, 2 screens, 47 wks, **LIGHTING** (med)
table nr -->		G12	G13	G14	G15	G16
duration of greenhouse use	weeks	23+21	22+10+18	22+10+18	21+11+15	21+11+15
target heating temperature	°C	19	19	19	19	19
maximum Relative Humidity	%	86	86	86	86	86
CHP (cogeneration)	W/m^2 (elc)	50	50	50	50	47
CHP run time	**hours/year**	**2449**	**3016**	**2880**	**2828**	**4285**
insulation value screen(s)	%	40 + 20	40+35F	40 + 20	40+35F	40 + 20
lighting (intensity; duration)	W/m^2; h/y	xx	xx	xx	xx	**72; 4100**
CO2 injection rate (own; purchased)	kg/ha/h	150; 75	150; 75	150; 75	150; 75	**150; 75**
production (pieces)	$pieces/m^2$	207	199	201	173	254
production (weight)	$\mathbf{kg/m^2}$	**85**	**85**	**87**	**74**	**109**
profit estimate	$Euro/m^2$	42	35	36	35	45
natural gas for cogenerator	m^3/m^2	33.2	40.8	39	38.3	58.0
natural gas for boiler	m^3/m^2	5.7	8.8	9.3	7.1	1.1
gas for climate control (1)	m^3/m^2	38.9	49.6	48.3	45.4	59.1
gas for climate control (2)	kWh/m^2	381	486	473	445	579
gas for climate control (3)	GJ/m^2	1.37	1.75	1.70	1.60	2.08
electricity purchased	kWh/m^2	8	8	8	9	8
electricity sold	kWh/m^2	-122	-122	-122	-141	-122
electricity - other on-farm	kWh/m^2	-10	-10	-10	-10	-10
electricity climate control (1)	kWh/m^2	-124	-124	-124	-142	-124
electricity climate control (2)	GJ/m^2	-0.45	-0.45	-0.45	-0.51	-0.45
CO2 purchased (1)	kg/m^2	9.3	9.3	9.3	8.2	9.3
CO2 purchased (2)	kWh/m^2	46	46	46	40	46
CO2 purchased (3)	GJ/m^2	0.16	0.16	0.16	0.14	0.16
total energy excl. CO2 (1)	kWh/m^2	257	362	349	303	455
total energy excl. CO2 (2)	GJ/m^2	0.92	1.30	1.25	1.09	1.63
total energy incl. CO2 (1)	$\mathbf{kWh/m^2}$	**303**	**408**	**395**	**343**	**501**
total energy incl. CO2 (2)	$\mathbf{GJ/m^2}$	**1.09**	**1.46**	**1.42**	**1.23**	**1.80**
total energy incl. CO2 per kg (1)	**kWh/kg**	**3.56**	**4.77**	**4.56**	**4.61**	**4.59**
total energy incl. CO2 per kg (2)	**MJ/kg**	**12.78**	**17.12**	**16.38**	**16.56**	**16.48**

Table 5c. Details of energy use for growing various types of tomatoes in glasshouses in the Netherlands with some variations in growing techniques. (Data source: KWIN, 2019).

		Tomatoes with CHP (& boiler)				
		Tom, cherry loose, 1 screen, 50 wks	Tom, cocktail truss, 1 screen, 50 wks, **LIGHTING (high)**	Tom, round, 1 screen, 50 wks	Tom, truss, fine, 1 screen, 51 wks	Tom, truss, heavy, 1 screen, 50 wks
table nr -->		G30	G31	G32	G33	G34
duration of greenhouse use	weeks	50	50	50	51	50
target heating temperature	°C	18	18	18	18	18
maximum Relative Humidity	%	87	87	87	87	87
CHP (cogeneration)	W/m^2 (elc)	50	50	50	50	50
CHP run time	hours/year	2919	3517	2919	3003	2919
insulation value screen(s)	%	40	40	40	40	40
lighting (intensity; duration)	W/m^2; h/y	xx	**110; 2400**	xx	xx	xx
CO2 injection rate (own; purchased)	kg/ha/h	150; 75	**150; 75**	150; 75	150; 75	150; 75
production (pieces)	$pieces/m^2$	xx	xx	xx	xx	xx
production (weight)	**kg/m^2**	**30.7**	**40.4**	**67.4**	**52.6**	**73.4**
profit estimate	$Euro/m^2$	43	45	34	37	35
natural gas for cogenerator	m^3/m^2	39.5	47.6	39.5	40.7	39.5
natural gas for boiler	m^3/m^2	11.5	1.6	11.6	12.3	11.6
gas for climate control (1)	m^3/m^2	51	49.2	51.1	53	51.1
gas for climate control (2)	kWh/m^2	500	482	501	519	501
gas for climate control (3)	GJ/m^2	1.80	1.73	1.80	1.87	1.80
electricity purchased	kWh/m^2	10	141	10	10	10
electricity sold	kWh/m^2	-146	-67	-146	-150	-146
electricity - other on-farm	kWh/m^2	-10	-10	-10	-10	-10
electricity climate control (1)	kWh/m^2	-146	64	-146	-150	-146
electricity climate control (2)	GJ/m^2	-0.53	0.23	-0.53	-0.54	-0.53
CO2 purchased (1)	kg/m^2	12.0	12.3	12.0	12.0	12.0
CO2 purchased (2)	kWh/m^2	59	60	59	59	59
CO2 purchased (3)	GJ/m^2	0.21	0.22	0.21	0.21	0.21
total energy excl. CO2 (1)	kWh/m^2	354	546	355	369	355
total energy excl. CO2 (2)	GJ/m^2	1.27	1.96	1.27	1.33	1.27
total energy incl. CO2 (1)	**kWh/m^2**	**413**	**606**	**414**	**428**	**414**
total energy incl. CO2 (2)	**GJ/m^2**	**1.48**	**2.18**	**1.48**	**1.54**	**1.48**
total energy incl. CO2 per kg (1)	**kWh/kg**	**13.44**	**15.01**	**6.14**	**8.14**	**5.63**
total energy incl. CO2 per kg (2)	**MJ/kg**	**48.25**	**53.94**	**22.03**	**29.23**	**20.23**

Table 5d. Continued: Details of energy use for growing various types of tomatoes in a glasshouse in the Netherlands with some variations in growing techniques. (KWIN, 2019).

		Tom with CHP (& boiler)			Tom without CHP	
		Tom, truss, heavy, 1 screen, 50 wks, **LIGHTING** (high)	Tom, truss med., 1 screen, 51 weeks	Tom, beef, 1 screen, 50 wks,	Tom, truss, heavy, 1 screen, 50 wks, buy CO2	Tom, truss heavy, 1 screen, 50 wks fluegas CO2
table nr -->		G37	G38	G39	G35	G36
duration of greenhouse use	weeks	50	51	50	50	50
target heating temperature	°C	18	18	18	18	18
maximum Relative Humidity	%	87	87	87	87	87
CHP (cogeneration)	W/m^2 (elc)	50	50	50	xx	xx
CHP run time	hours/year	**3825**	**3003**	**2919**	**xx**	**xx**
insulation value screen(s)	%	40	40	40	40	40
lighting (intensity; duration)	W/m^2; h/y	**110; 3200**	xx	xx	xx	xx
CO2 injection rate (own, purchased)	kg/ha/h	**150; 75**	150; 75	150; 75	150; 75	150; 0
production (pieces)	$pieces/m^2$	xx	xx	xx	xx	xx
production (weight)	**kg/m^2**	**93.3**	**64.4**	**68.3**	**73.4**	**73.4**
profit estimate	$Euro/m^2$	42	34	34	31	31
natural gas for cogenerator	m^3/m^2	51.8	40.7	39.5	0	0
natural gas for boiler	m^3/m^2	1.1	12.3	11.5	34.4	**42.1**
gas for climate control (1)	m^3/m^2	52.9	53	51	34.4	42.1
gas for climate control (2)	kWh/m^2	518	519	500	337	413
gas for climate control (3)	GJ/m^2	1.86	1.87	1.80	1.21	1.48
electricity purchased	kWh/m^2	211	10	10	10	10
electricity sold	kWh/m^2	-23	-150	-146	0	0
electricity - other on-farm	kWh/m^2	-10	-10	-10	-10	-10
electricity climate control (1)	kWh/m^2	178	-150	-146	0	0
electricity climate control (2)	GJ/m^2	0.64	-0.54	-0.53	0.00	0.00
CO2 purchased (1)	kg/m^2	13.1	12	12	**13.9**	0
CO2 purchased (2)	kWh/m^2	64	59	59	68	0
CO2 purchased (3)	GJ/m^2	0.23	0.21	0.21	0.25	0.00
total energy excl. CO2 (1)	kWh/m^2	696	369	354	337	413
total energy excl. CO2 (2)	GJ/m^2	2.50	1.33	1.27	1.21	1.48
total energy incl. CO2 (1)	**kWh/m^2**	**761**	**428**	**413**	**405**	**413**
total energy incl. CO2 (2)	**GJ/m^2**	**2.73**	**1.54**	**1.48**	**1.46**	**1.48**
total energy incl. CO2 per kg (1)	**kWh/kg**	**8.15**	**6.65**	**6.04**	**5.52**	**5.62**
total energy incl. CO2 per kg (2)	**MJ/kg**	**29.30**	**23.87**	**21.69**	**19.84**	**20.19**

[5] REFERENCES / LITERATURE

KWIN, 2019. Kwantitatieve Informatie voor de Glastuinbouw 2019. Raaphorst & Benninga. Rapport WPR-889. Wageningen University & Research, The Netherlands. 290 pages.

Energiemonitor van de Nederlands glastuinbouw 2018. (2019). Van der Velden & Smit. Rapport 2019-111. Wageningen University & Research, The Netherlands. 60 pages.

Energiemonitor van de Nederlands glastuinbouw 2020. (2021). Smit and Van der Velden. Rapport 20. 2021-127. Wageningen University & Research, The Netherlands. 60 pages.

New Zealand Energy Information Handbook. 2008. Eng, Bywater and Hendtlass. University of Canterbury. 126 pages.