

# OPTIMUM INTEGRATION OF POLYGENERATION IN THE FOOD INDUSTRY - QUANTIFYING THE TECHNICAL POTENTIAL IN THE FOOD TRANSFORMATION INDUSTRY

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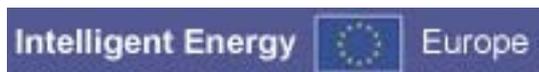
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## **1. INTRODUCTION**

The overall aim of this paper is to investigate and perform a first estimation of the general potential for polygeneration in the food industry in the EU-15 countries of Europe.

### **DEFINITION OF POLYGENERATION**

Polygeneration is the use of multiple primary energy inputs to create multiple energy outputs.

Energy output means the different forms of energy which are useful in an activity. In the case of the food industry this could mean electricity, and heat in various temperature levels i.e. steam, hot water, chilling mediums etc. Other useful products, which might come out from a polygeneration process like e.g. compost fibers will be treated as secondary by-products of polygeneration.

### **DEFINITION OF FOOD SECTORS**

In order to come up with aggregate figures, the food processing industry was divided into 7 main sectors covering different kinds of food products.

The seven food sectors are:

- I. Fish and meat (fresh, frozen, cooked)
- II. Cooked food & vegetables.
- III. Oils, fats, olive oil
- IV. Beverages, juices, brewery, wine and spirits.
- V. Flours, cereals, corn, pastry, bakery, coffee and tea.
- VI. Chocolate, sugar & confectioneries.
- VII. Dairy, milk and ice-creams

In this paper, only the general results and findings are described and discussed. The details on the processes and the sub-sector detailed results can be found in the Optipolygen WP2 Report available on the project's website.

## 2. PROCESS DESCRIPTIONS

In general, almost all food processing requires both electric power as well as heat for some kind of thermal processing. Electric power is required for mechanical processing such as pumping, ventilating, mixing and conveying etc., besides cooling by mechanical compression coolers.

The required thermal processes include both high temperatures processing as well as low temperature processing. In Table 1 the most common thermal processes are listed and indicated in which food sector they are predominating.

Table 1: Summary of some of the most common thermal processes used in the food processing industry, indicated for each food sector

Thermal Process	Temp	Food Sector					
		I	II	V	I	II	
Cooling, chilling	4 to 8°C	X	X	X	X	X	X
Freezing	-15 to -40°C	X	X		X		X
Blanching	80 °C		X				
Cooking, boiling, frying	90 to 150°C or 100 to 300°C	X	X	X			
Degumming	100 °C			X			
Roasting	370 to 540°C (coffee) 130 to 150 °C (cacao)				X	X	
Pasteurisation	72°C			X			X
Bleaching	150 °C			X			
Deodorization	180 – 270 °C			X			
CIP	> 50°C		X		X		X
Baking	300 to 400 °C				X		
Distillation, Evaporation	> 100 °C				X		X
Proofing	40°C				X		
Defrosting	20 to 40 °C						
Freeze storage	-18 to -40°C	X	X				X
Cooled storage	4 to 8 °C		X		X	X	X
Air condition	10 to 20 °C	X					

### 3. SPECIFIC ENERGY REQUIREMENTS

In order to be able to estimate the total potential for polygeneration, the amount and type of energy required for the food processing has to be known or qualitatively approximated.

The specific electric power and thermal energy required for producing or processing one tonne of food product in the respective food sectors was calculated. Variations in the specific energy requirements for a same food product can be explained by differences in design, technology and also the scale of the plants investigated.

#### **4. PROCESS WASTE AND BY-PRODUCTS**

Many sectors of the food industry produce significant amounts of biodegradable waste or by-products that could be used for energy production. Typical values for the amounts of waste produced were estimated for each food sector as either kg solid or amount of chemical oxygen demand (COD).

#### **5. POTENTIAL AND FEASIBLE POLYGENERATION TECHNOLOGIES FOR ON-SITE ENERGY PRODUCTION**

Three technology options were considered for all food sectors. These were:

1. Co-generation of heat and electricity in a natural gas fired gas turbine.
2. Tri-generation by using heat from the gas turbine as a source for absorption cooling.
3. Usage of biodegradable waste streams for biogas production which in turn is used in the gas turbine.

The limitations in terms of size and operation of the technologies were taken into account.

##### **5.1. Cogeneration - CHP**

There are several CHP technologies available for on-site energy production, some of which are standard technology (gas engines, gas turbines, steam turbines), others more or less mature (Organic Rankine Cycle (ORC), Stirling engines, fuel cell technologies). In most food industries, steam is used for the heat transfer and thus

thermal energy at more than 100 °C is needed, explaining the selection of gas turbine technology as technology of choice.

### **5.2. Tri-generation - CHP combined with absorption cooling**

Tri-generation is based on the use of absorption cycles to produce cool using the exhaust heat energy from a CHP unit. The minimum commercial available absorption coolers are about 150 kW and their COP (Coefficient of Performance) ranges from 0.6 - 1 depending on the freezing cycle served and on the heat available.

### **5.3. Polygeneration -CHP using biogas from process waste as fuel**

Organic waste or by-products can be used to generate thermal energy and power at the plant by direct combustion, thermal gasification or anaerobically treated to produce biogas. This biogas can be combusted in gas burners or in CHP applications.

## **6. ENERGY USE IN THE FOOD INDUSTRY**

In order to estimate the potential for polygeneration in different food sectors, the total energy used in each food sector had to be estimated, mainly by combining the specific energy requirements defined in section 3 with best available statistical data for the production or processing of the each specific product.

Most of the data of produced amounts of food products were extracted from the EUROSTAT database PRODCOM<sup>1</sup>, but also other sources have been used when more recent and detailed data has been available elsewhere.

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<sup>1</sup> EUROSTAT, <http://epp.eurostat.ec.europa.eu>

Due to differences in nomenclatures used by EUROSTAT and OPTIPOLYGEN, some results (food and drink and tobacco industries) are indicative although the orders of magnitude are aligned.

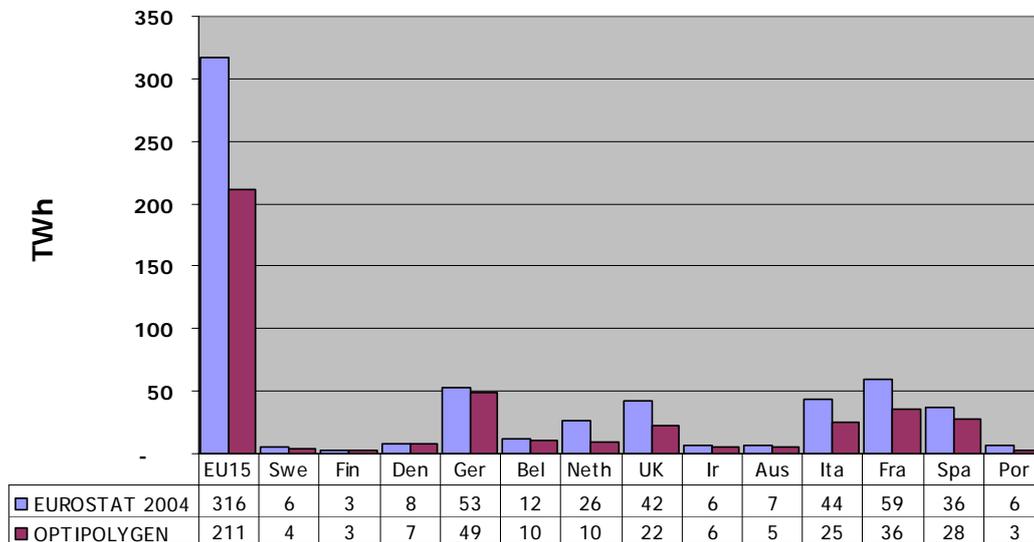


Figure 1: Energy consumption in food drink and tobacco compared to OPTIPOLYGEN calculations

When the energy use was further compared in terms of consumption of electric power and energy demand in form of heat, the general result is that the calculation of the electricity consumption is closer and sometime slightly overestimated compare to the EUROSTAT data. The total consumption of electricity in the “food, drink and tobacco industry” and the EU-15 countries is 94 TWh and according to the OPTIPOLYGEN calculations 88 TWh.

While the OPTIPOLYGEN calculations of electricity consumption are close and sometimes overestimated the calculated consumption of heat is lower than the EUROSTAT data (123 TWh instead of 222 TWh). This is an important fact as the calculation of the potential polygeneration potential described later on in this report is mainly limited by the amount of heat needed of each food processing plant. **Thus the calculated technical polygeneration potential in this report is more likely to be an underestimation than an overestimate.**

Moreover, the correlations of OPTIPOLYGEN results with the EUROSTAT database have to be seen as plausible and absolutely within the correct size range.

## **7. TECHNICAL POTENTIAL FOR POLYGENERATION IN THE FOOD PROCESSING INDUSTRY**

The investigation comprises the technical potential based upon estimated energy demands of the processes, without taking economic considerations into account.

The calculated potentials are the maximum technical potential including already implemented CHP and polygeneration in the food processing industry.

### **7.1. Methodologies used for the estimations of the technical potential for polygeneration**

Due to the lack of detailed data for energy use, size and number of food processing plants in Europe, two basic types of methodologies were developed for the estimations.

The first of the methodologies is based on the assumption that a certain production volume per employee can be estimated and thereby the number of plants (enterprises) having production capacities above a certain threshold value is used in the calculations of the total polygeneration potential. The number of employees was collected from EUROSTAT using the NACE code separation.

The second methodology is based upon detailed data from at least one country where the number and production distribution between existing food processing plants is known. By using this detailed information from one country, the production distribution in other EU-15 countries is estimated.

In some food sectors a hybrid methodology was in order to get useful results.

Based on this data, estimated total energy requirements (electrical and thermal) were calculated. Threshold values were also set, as some heat loads would be too small and dispersed.

## **7.2. Calculation of threshold values used for the estimations of co-, tri- and poly-generation**

### **Threshold estimation for co-generation:**

Currently, the smallest commercially available micro turbine are found at about 30<sup>2</sup> to 100 kWel, which are used as the threshold values in the calculations of most of the industries.

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Other requirement data used for the threshold calculations were a minimum peak-load hours of operation at 4000 h/year for all technologies. In addition, 50 % additional thermal load is required, due to the seasonal load variations. The ratio of thermal energy output to the electrical energy output is approximately 2.5 for micro turbines.

These values result in the minimum onsite heat load requirement of 450 MWh/year, rounded up to 500 MWh/year in the calculations. The same heat to electricity ratio (2.5) is used regardless of CHP technology or unit size.

### **Threshold estimation for tri-generation:**

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<sup>2</sup> Capstone Turbine Corporation, [www.capstoneturbine.com](http://www.capstoneturbine.com); December, 2005.

The smallest commercially available absorption cooler has presently 100 kW cooling capacity translating into about 125 kW thermal driving force in the deep freezing applications (COP  $\approx$  0.8) and about 85 kW in the refrigeration applications (around +4 °C; COP  $\approx$  1.2).

*Table 2 : Typical technical data used for the calculating cooling energy*

Cooling temperature	+ 4 °C	- 30 °C
Compressor cooling COP	2.5	1.2
Absorption cooling COP	1.2	0.8

### **Threshold estimation for biogas production (polygeneration)**

Two types of methodology were used to estimate the threshold value for the production of biogas from waste streams.

One methodology to define the threshold by assuming that the biogas reactor must produce as much biogas (methane) as is needed to feed the CHP unit, the other methodology to define the threshold from data indicating the smallest operative biogas reactor available which was set to 5 000 tons of solid waste/year.

The smallest available CHP unit (30 kW<sub>el</sub>) sets the threshold for the biowaste utilisation.

Sect.	Food Product	Co-generation Tonnes processed /year	Tri-generation	Biogas production
I	Fish	4 000	989	10 417
	Meat	1 875	1 552	35 519
Tonnes product/year				
III	Cotton seed	1 700	n.a.	3 000
	Ground nut	3 000	n.a.	Solid
	Rape-seed	2 500	n.a.	Biomass
	Safflower	2 500	n.a.	
	Sesame	3 000	n.a.	17 000
	Sunflower	2 500	n.a.	Biogas
	Soybean	1 100	n.a.	
V	Corn	1 640	1 640	283 843
	Bakery	8 857	3 490	577 778
	Cereals	n.a.	n.a.	19 923
	Coffee	2 708	788 <sup>1</sup>	n.a.
VI	Sugar	400 000	n.a.	6 410
	Chocolate	82 286	18 581	n.a.
VII	Milk	11 719	32 727	n.a.
	Cheese	1 250	6 000	32 581
	Butter	1 531	14 619	n.a.
	Milk powder	429	10 286	n.a.
	Ice Cream	1 875	3 333	n,a
	Cultured products	11 538	32 727	n.a.
hl product / year				
IV	Beer	22 721	27 975	217 391
	Spirits	4 972	n.a.	71 429
		hl pure alcohol		
Juice	15 790	n.v.	400 000	
Number of employees in the factory				
II	Cooked food & Vegetables		17	20
				96

Table 3 : Used threshold values for the potential evaluation in the different food sectors

Explanations:

1..... freeze-dried coffee,

n.a.... not applicable according to estimation calculations,

n.v....no values available

By defining biogas as having an energy content of 6 kWh/Nm<sup>3</sup> and setting a min energy requirement of 450 MWh/year, determined by the CHP unit, a minimum production of 75 000 Nm<sup>3</sup> biogas is required.

An average value of 400 Nm<sup>3</sup>/ton of volatile solids (VS) or 0.35 Nm<sup>3</sup>/ton per kg COD for the calculations which in turn give threshold values of 190 ton VS/year or 215 kg COD/year respectively.

### **7.3 Results of estimated technical polygeneration potentials**

The results of the calculations are shown in total electrical energy per year, which can be generated if the existing methodologies separated by co- or tri-generation or energy production of waste streams (biogas or solid biomass waste CHP combustion) take place in the EU-15 countries, split by food sector.

In the food sector III, large quantities of solid biomass residues occurs which are not suitable for biogas production but could instead be used as a solid biomass fuel in CHP unit (steam turbine). Thus for this food sector a fourth methodology is added. By summing up the calculated values for all four methodologies (co-, tri- and waste stream utilisation) the total polygeneration potentials are revealed.

The main part of the total polygeneration potential is made up from co-generation (56%). The possibility for co-generation is also the basic for the other methods and technologies are more or less add-ons to this type of technology.

Moreover, the results in **Figure 3** show that the single largest technical potential for polygeneration is found in the meat industry (food sector I). About half of this potential is by co-generation and the other half from tri-generation by absorption

cooling. The beer and the sugar industry do also show quite high potentials for especially co-generation. In the cereal industry a remarkable potential for utilisation of waste streams for biogas production is revealed.

By instead looking at the technical potentials divided by each country in the EU-15 (**Figure 4**), the largest potentials for polygeneration in the food sector are found in the highly populated countries Germany, France, Spain , UK and Italy.

Total polygeneration potential in EU 15: **73,1 TWh<sub>el</sub>**

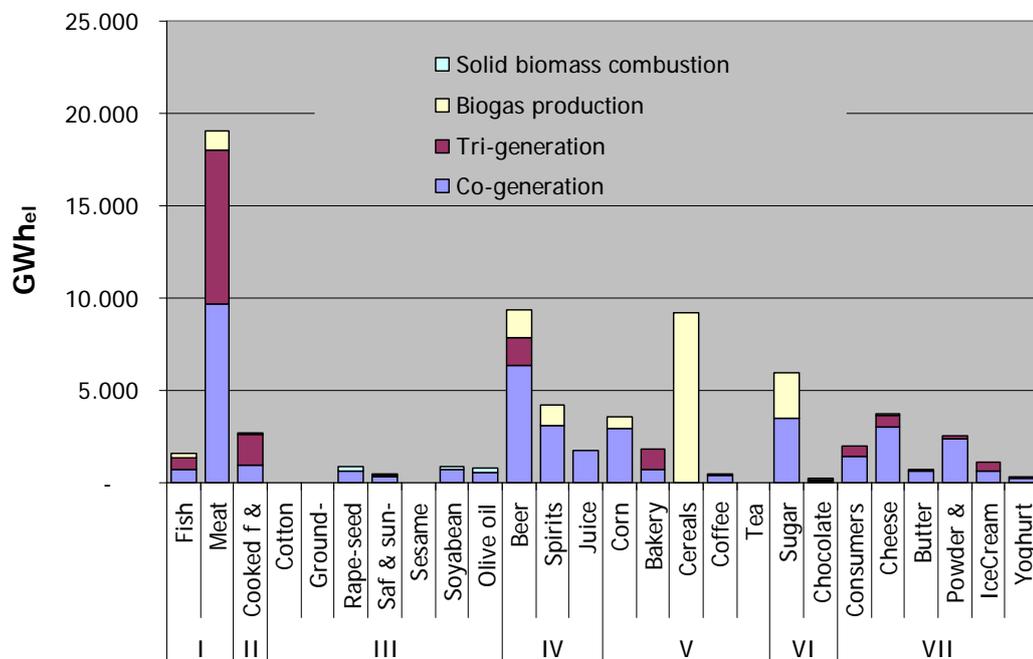


Figure 2 : Technical polygeneration potential by food sector

Total polygeneration potential in EU 15: **73,1 TWhel**

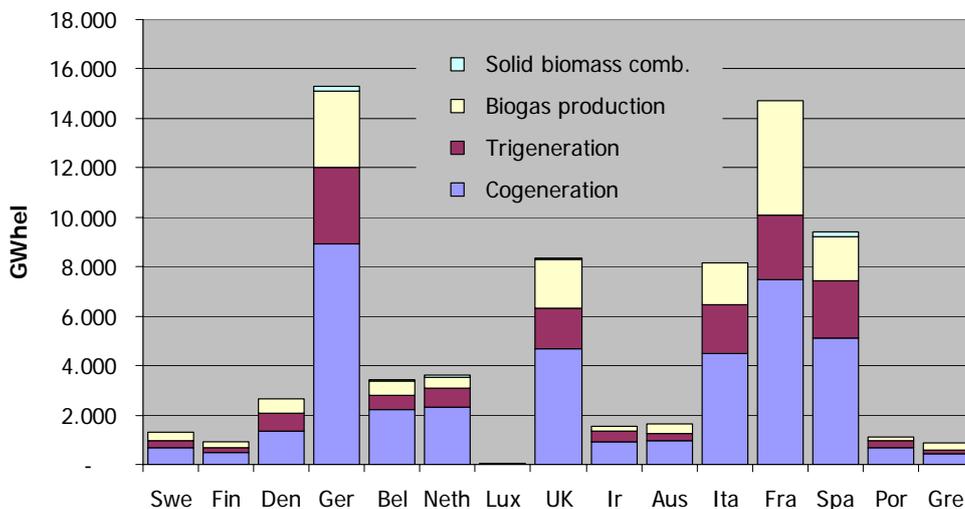


Figure 3: Technical polygeneration potential by EU-15 country

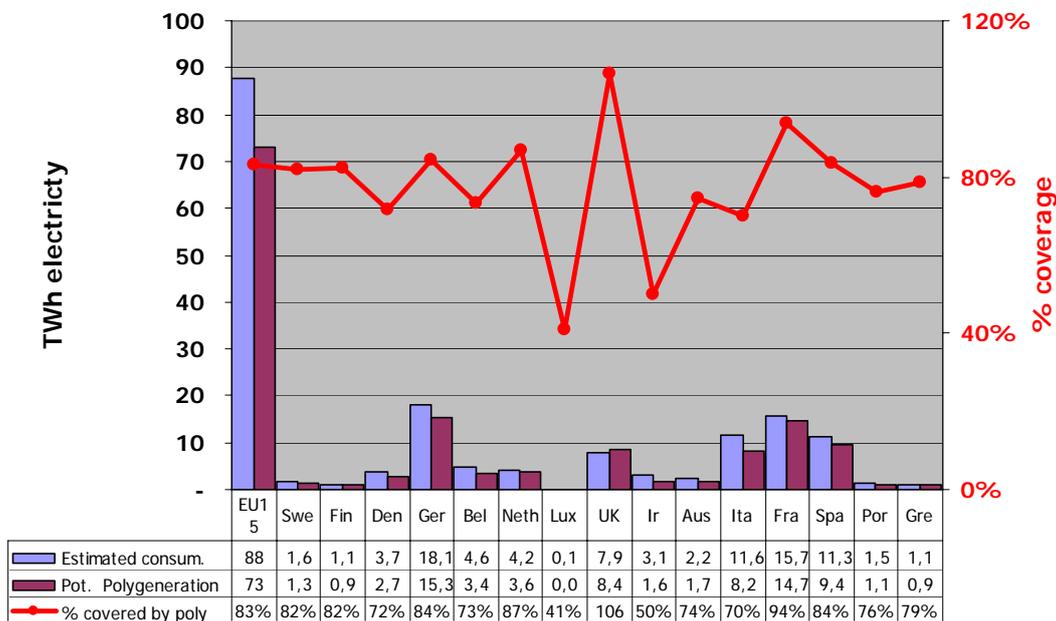


Figure 4: Technical potential coverage of electricity demand by polygeneration in EU-15 country

## 7.4 Implemented CHP capacity compared to the technical potential of co-generation

According to data collected by COGEN Europe for the year 2003, there are 595 CHP units installed in the “food, beverage and tobacco industry” in EU-15<sup>3</sup>. Together they have a total production capacity of 3048 MW<sub>el</sub>, when running in High Efficiency CHP mode. The countries with the currently highest implementation and utilisation of CHP within this industry are Spain, UK, Germany, France and the Netherlands. It is also noticeable that some countries such as Finland, Greece and Luxembourg are supposed to have no CHP units installed. This is probably due to incomplete data as the OPTIPOLYGEN project has identified at least one Finnish CHP unit of 4.2 MW<sub>el</sub> (see database at [www.optipolygen.org](http://www.optipolygen.org)).

The data collected in the COGEN statistics is collected for the “Food products, beverages and tobacco” industry and is thus not 100% comparable to the technical potential calculated for “food and drink” industry in the OPTIPOLYGEN project. However they are a good indication and thereby the total amount of produced electricity from CHP units (running in CHP mode) are used as comparison to the OPTIPOLYGEN values in **Figure 5**.

The result reveals that in 2003, 10.76 TWh<sub>el</sub> was produced from CHP-units in the “Food products, beverages and tobacco” industry in EU-15. This is about ¼ of the technical potential for co-generation estimated for the food and drink industry in the OPTIPOLYGEN project.

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<sup>3</sup> CHP Statistics in European Member States 2003 data, COGEN EUROPE 2005

Tot (EU-15) produced by CHP in food, drink and tobacco industry 10,76 Twhel (COGEN 2003)

Tot estimated CHP potential (EU15) in food, drink industry 40,78 Twhel (OPTIPOLYGEN 2004)

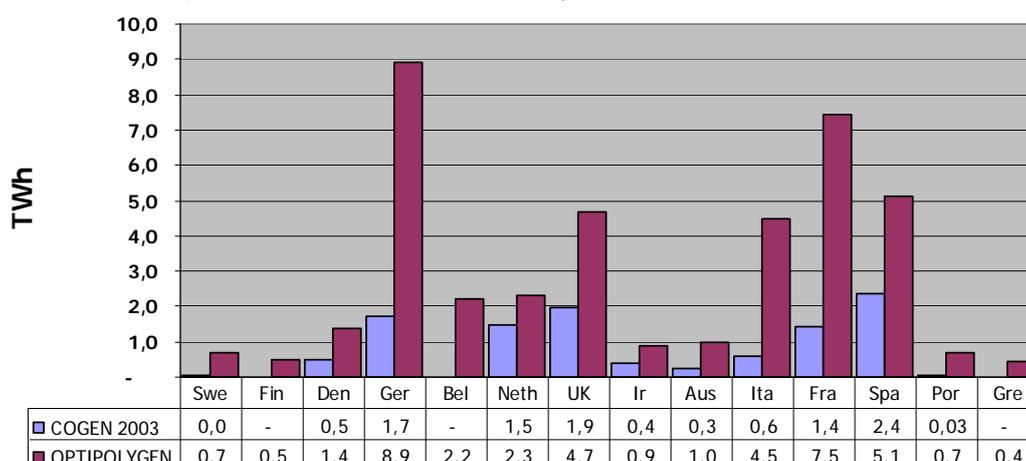


Figure 5: Produced electric power by CHP units in the food, beverage and tobacco industry in EU-15 (2003) compared to technical potential for CHP in the food and drink estimated by OPTIPOLYGEN

## 7.5 Result of estimated CO<sub>2</sub> –saving potential

In addition to the potential for electricity generation, the environmental impact of polygeneration can also be quantified in terms of annual CO<sub>2</sub> savings. This is done assuming that the additional on-site electricity generated is produced with a higher efficiency (due to higher efficiency of combined cycles) and thereby replaces electricity produced from fossil fuels in power plants and distributed via the grid.

By using the values for grid transmission losses and for CHP total cycle efficiencies, the values of CO<sub>2</sub> savings by the different polygeneration methodologies were calculated as:

- 0,26 kg CO<sub>2</sub>/kWh<sub>el</sub> for co-generation;
- 0,436 kg CO<sub>2</sub>/kWh<sub>el</sub> for tri-generation;
- 0,210 kg CO<sub>2</sub>/kWh<sub>el</sub> for waste stream utilisation

By using these figures the total results for the potential CO<sub>2</sub> savings by polygeneration in the food industry in the EU-15 amounts to 20 839 ktonnes CO<sub>2</sub>/year.

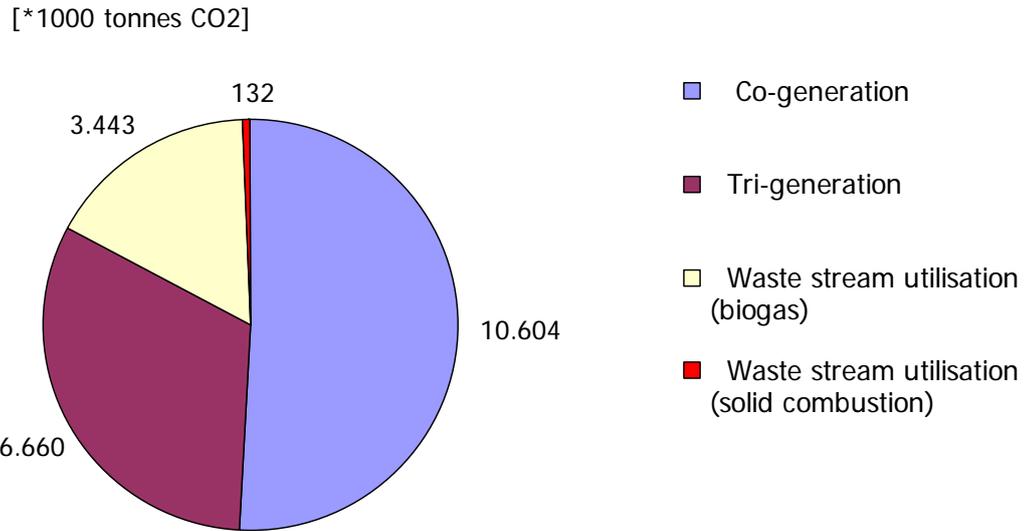


Figure 6: Summarised technical potential of CO<sub>2</sub>-savings in the food industry by polygeneration methodologies

Total potential CO<sub>2</sub> savings by polygeneration in EU 15: **20 839 ktonnes CO<sub>2</sub>/year**

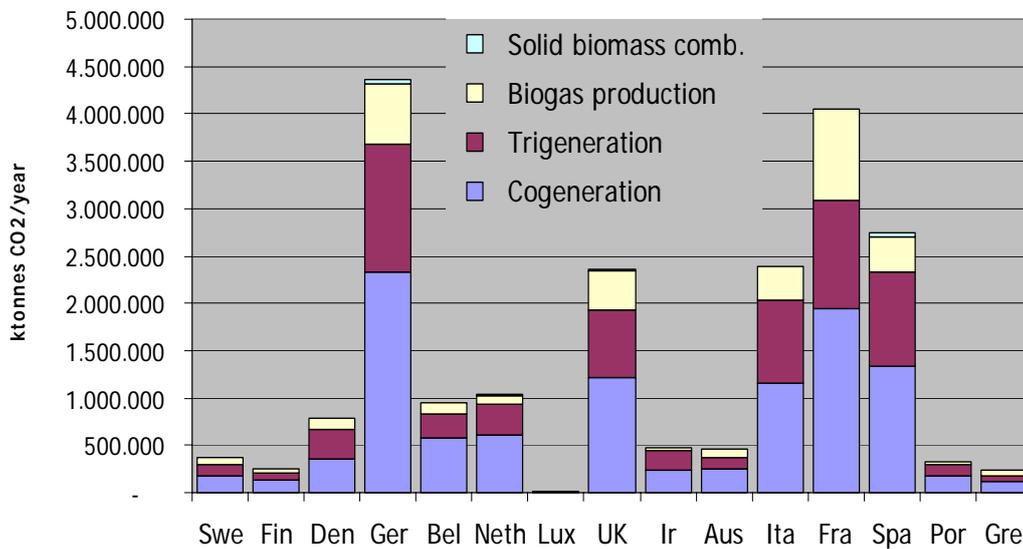


Figure 7: Summarised technical potential CO<sub>2</sub>-savings in the food industry by polygeneration per EU-15 country

The revealed figures for saving CO<sub>2</sub> emissions by the technical potential in the food industry are calculated without withdrawing the current installed CHP capacity.

Given the assumption that about  $\frac{1}{4}$  of the technical potential from co-generation is already implemented, the total actual potential should be reduced to about 18 188 ktonnes CO<sub>2</sub>/year instead.

## 8. MAIN RESULTS AND CONCLUSIONS

The technical polygeneration potential for the food industry has been calculated for the EU-15 countries.

**The calculated results reveal a total technical polygeneration potential (co- + tri-generation and full utilisation of biomass waste stream) for all EU-15 countries to amount to about 73 TWh<sub>el</sub>/year, subsequently resulting in a potential CO<sub>2</sub> emission saving of about 20 millions tonnes CO<sub>2</sub>/ year.**

**More than half of the technical potential for polygeneration in the food industry is identified to be co-generation.** By comparing with available data of installed capacities of CHP in the food, beverage and tobacco industry with OPTIPOLYGEN results, it can be *assumed* that up to  $\frac{1}{4}$  of the calculated technical potential is already installed.

This would mean that the *additional* total technical polygeneration potential is about 63 TWh<sub>el</sub> and subsequently the additional potential CO<sub>2</sub> emission savings by polygeneration to about 18 million tonnes CO<sub>2</sub>/year.

The high potential of co-generation is followed by tri-generation and the technical potential for converting waste streams into biogas which is subsequently used in on-site CHP applications. Both these technologies revealed technical potentials of about 16 TWh<sub>el</sub> each.

The fourth technology investigated was the utilisation of solid waste used as solid biomass fuel in a CHP plant using a steam turbine cycle. This technology was however only found feasible for the food sector III and was estimated to be around 0,6 TWh<sub>el</sub> for the whole EU-15.

The highest technical polygeneration potential is found in the meat processing industry (food sector I). Other industries with significant technical potentials are beer production (food sector IV) and cereal production (food sector V).

With respect to the distribution of the technical potential for polygeneration in the food industry among the European countries (EU-15), the potential practically follows the population distribution in the same way as the production and consumption of food does. Thereby the largest technical potentials are typically found in the order Germany, France, Spain, UK and Italy.

By comparing data for the electric power produced by CHP in the “food, beverage and tobacco” industry with the amounts consumed, this shows production that on an average covers about 12% of the demand in EU-15 (2003). By applying the total technical polygeneration potential calculated for the food industry in the OPTIPOLYGEN project this figure would be increased to about 80% (2004).

