# ENERGETIC VALORIZATION OF GRAPE STALKS: AN ENVIRONMENTAL ANALYSIS THROUGH LIFE CYCLE ASSESSMENT

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**Abstract**

*Portugal has historically been a big wine producer. It produced 7 million hectoliters of wine in 2015-16 campaign, generating 24.5 million kg of grape stalks that can be used for Bioenergy. The aim of this study was to quantify the potential environmental impacts associated with grape stalks when they are used as fuel in a furnace to produce heat and identify the "hotspots", using the Life Cycle Assessment methodology. The method chosen for environmental impact assessment was CML-IA baseline V3.04 available in the software SimaPro8.3.0. The results show that heat production from pellets made with grape stalks is more environmentally harmful in terms of "marine aquatic ecotoxicity" and it is due to electricity mainly used in the "pellets production" and "heat production" processes. Electricity use is the "hotspot" presenting a great potential for environmental improvement of the product system.*

**Key words:** *bioenergy, grape stalks, lca, pellets, pine wood*

## 1. INTRODUCTION

The world´s area under vines in 2015 was 7.5 millions hectares (mha) with a global production of grapes of 75.7 millions tons (mt) and wine production of 274 millions hectoliters (mhl) (OIV 2016). Five countries represent 50% of the world vineyard (Spain 14%, China 11%, France 10%, Italy 9% and Turkey 7%) and 40% of total world grape is produced in Europe, 31 % in Asia and 20% in America. The global market (exports) reached 104.3 mhl in terms of volume and 28.3 billion EUR in terms of value.

Portuguese area under vines, in 2015, was 0.217 mha with a wine production of 7 mhl representing 2.89% and 2.55% of the world´s area under vines and wine production, respectively (IVV 2016; OIV 2016). The exports achieved a volume of 2.8 mhl and a value of 0.7 billion EUR.

It is estimated that the winery activities generated, in 2015, almost 7.3 mton of organic wastes worldwide and 186200 tons in Portugal, considering the indices of organic wastes generated by hectoliter of wine (Silva 2003). The majority of Portuguese organic wastes was grape pomace (101500 tons), followed by lees (32200 tons), seeds (28000 tons) and stalks (24500 tons) which means that there is a great potential to implement a valorization strategy.

Grape pomace and lees are being used as by-products (Mendes et al. 2013; Silva 2003) whereas the stalk has been traditionally incinerated or disposed in landfill, however, composting is proposed for the recovery of stalks (Ruggieri et al. 2009) to produce a sanitized organic amendment for application in the vineyard. The stalk moisture content is about 100% and its calorific value is in the range of 2000 to 2500 calories / kg and its use as fuel is absolutely viable (Silva 2003).

Life Cycle Assessment (LCA) is a method for compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (International Organization for Standardization 2006a, 2006b). LCA has been applied to a wide range of products and services such as on waste management strategies in general (Heijungs & Guinée 2012; Ferreira, Esteves & Domingos 2015; Ferreira et al. 2016) and on winery activities in particular (Marçal 2014).

The main aim of this study was to quantify the potential environmental impacts associated with grape stalks when they are used as fuel in a furnace to produce heat and identify the hotspots using the Life

Cycle Assessment methodology. This work was done in the frame of the project ACVPEL (PROJ/CI&DETS/2017/27).

## 2. METHODOLOGY

The LCA study was performed based on ISO 14040 (International Organization for Standardization 2006a) and ISO 14044 (International Organization for Standardization 2006b) series of standards recommended methodology, so it was divided into four phases: goal definition – which defines the aim and scope of the study as well as the functional unit (a measure of the function of the studied system); inventory analysis – which lists emissions of pollutants into air, water and soil, solid wastes and consumption of resources per functional unit; impact assessment – which assesses the environmental impact of the pollutants emitted throughout the life cycle; and interpretation of results.

### *2.1 Goal and scope of the study*

The aim of the study was to evaluate the potential life cycle environmental impacts associated with pellets made from grape stalks when they are burning in a furnace to produce heat and identify hotspots. The results are to be used by the companies to improve the environmental performance of the product and processes.

#### *2.1.1 Function of the study and functional unit (FU)*

The function of the system in study is to produce heat for different uses. Therefore, the functional unit (FU) assumed was 1 MJ of heat outside furnace 15 KW, released from the combustion of grape stalks pellets. The choice of this functional unit is in agreement with other Bioenergy systems studied from an LCA perspective (Dones et al. 200; González-García, Mola-Yudego & Murphy 2013).

#### *2.1.2 System boundary*

The system boundary for the product system in study is represented in a simplified way in Fig.1. The modules included in boundaries are: pellets production (chopper + press) and boiler operation. Grape stalks are an output of the wine production process considered without economic value.

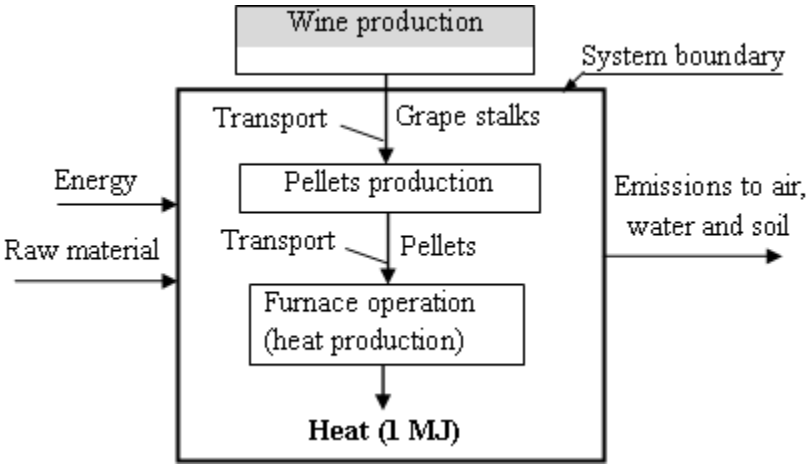


**Fig. 1.** Product system boundary

*2.1.3 Allocation procedure*

Grape stalks have no burdens allocated because they are considered without economic value at the wine production process. Pellets production and boiler operation are unit processes so, all their inputs and outputs are allocated to the pellets and heat, respectively.

*2.2 Inventory analysis*

The inventory analysis and, subsequently, the impact analysis have been performed using the LCA software SimaPro 8.3.0.0 (PRé 2016) and associated databases and methods.

*2.2.1 Data type/data collection*

A pilot plant was used to model datasets for the product and processes included in the system boundary. Elementary composition of raw-material (grape stalks), calorific values of pellets and amount of ash were determined. To produce 1 $m^3$ of stalk pellets with a bulk density of 671 $Kg/m^3$, a moisture content of 10% and a low calorific value of 15.3 MJ/Kg, were needed 2.21 $m^3$ of grape stalks with a bulk density of 304 $Kg/m^3$ and 73.3 KWh of electricity.

Transport distance of grape stalks, depend on local conditions so, it was assumed an average transport distance of 100 Km by rail and 50 Km by lorry 16-32 ton. Similarly, transport distance of pellets between production and combustion sites depend on local conditions and may be differ with type of heating system so it was assumed an average transport distance of 100 Km by lorry 16-32 ton, as proposed to wood pellets in (Dones et al. 2007).

The pellets were assumed to be burned in a furnace, 15 KW and $\eta$=82%. To produce 1MJ heat outside the furnace were needed $1.190x10^{-4}$ $m^3$ of stalk pellets and $4.17x10^{-3}$ KWh of electricity. Emissions data for pellets combustion are presented in Table1. $CO_2$ and $SO_2$ are based on calculus considering a complete combustion. CO and $NO_x$ emissions were provided from a smoke gas analyzer (Testo 350 XL) put on pilot combustion unit and the data have been multiplied by a correction factor of 1.32 and 1.1, respectively, in order to reflect realistic operational conditions of furnace (Dones et al. 2007). Furthermore, $2.31x10^{-3}$ kg of grape stalks ashes were produced and sending to landfill.

| Emissions to air (Kg/MJ of heat)<br>Name | **Grape stalks pellets** |
|---|---|
| **$CO_2$** | 0,1185 |
| **$SO_2$** | $6,52x10^{-5}$ |
| **CO** | $3.46\ x10^{-3}$ |
| **$NO_x$** | $1.06\ x10^{-4}$ |

**Table 1.** Air emissions from pellets combustion

The inventory datasets for the background system (such as electricity, etc.) were obtained and adapted as necessary from Ecoinvent database available in SimaPro 8.3.0.0 software as recorded in Table 2.

| **Process** | **Equivalent process** | **Source in SimaPro 8.3.0.0 software** |
|---|---|---|
| Pellet manufacturing, infrastructure | Wood pellet manufacturing, infrastructure/RER/I U | Ecoinvent 3 database |
| Heat production | Pellets, mixed, burned in furnace 15kW/CH U | Ecoinvent 3 database (adapted for this study) |
| Furnace production (infrastructure) | Furnace, pellet, 15kW {CH}\| production \| Alloc Def, U | Ecoinvent 3 database |
| Ash on sanitary landfill | Wood ash mixture, pure {Europe without Switzerland}\| treatment of wood ash mixture, pure, sanitary landfill \| Alloc Def, U | Ecoinvent 3 database (adapted for this study) |
| Electricity | Electricity, low voltage {PT}\| market for \| Alloc Def, U | Ecoinvent 3 database |
| Transport by lorry | Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}\| market for \| Alloc Def, U | Ecoinvent 3 database |
| Transport by train | Transport, freight train {Europe without Switzerland}\| market for \| Alloc Def, U | Ecoinvent 3 database |

**Table 2.** Datasets for the background system

The equivalent process for heat production was adapted for this study considering the air emissions of grape stalks pellets combustion as registered in Table 1. The equivalent process for ash on sanitary landfill was adapted considering the chemical composition of grape stalks determined in a previous study (Prozil, Evtuguina & Cruz-Lopes 2012).

### *2.3 Life cycle impact assessment (LCIA)*

The method chosen for environmental impact assessment was CML-IA (baseline) V 3.04/World 2000, that elaborates the problem-oriented (midpoint) approach and account for the World as an reference system for Normalization (Guinée et al. 2002; Pré 2016). The impact categories addressed are: abiotic depletion (AD); abiotic depletion (fossil fuels) (AD(FF)); global warming (GWP100a) (GW); ozone layer depletion (ODP) (OD); human toxicity (HT); fresh water aquatic ecotoxicity (FWET); marine aquatic ecotoxicity (MAET); terrestrial ecotoxicity (TET); photochemical oxidation (PO); acidification (AC); and eutrophication (EU).

## 3. RESULTS

The environmental profile of the functional unit (1 MJ of heat outside furnace 15 KW, released from the combustion of grape stalks pellets) using the CML-IA (baseline) method is shown in Figure 2 and Table 3. The results show that pellets production (pellets at store house) is the flux that most contributes for *abiotic depletion (FF)*, *global warming*, *ozone layer depletion* and *ecotoxicity (marine aquatic and terrestrial)* mainly (>70%) due to the electricity used in the pellets production. Burning the pellets in the furnace for "heat production" is the process responsible for almost 97% of *photochemical oxidation*, it is very important (>50%) for *acidification* and *eutrophication* and still has significant importance (31.8%) for *human toxicity*. Transport by lorry contributes significantly for *ozone layer depletion* (31.7), *abiotic depletion (FF)* (23.3%), *abiotic depletion* (18.9%) and *global warming* (16.8%) mainly due to the "pellets transport" process. "Ash treatment on sanitary landfill" is only of importance for *fresh water aquatic ecotoxicity* representing 35.2% of its total. The contribution of "Furnace production" for environmental profile ranges from 0.6% for *photochemical oxidation* up to 48.7% for *abiotic depletion*.

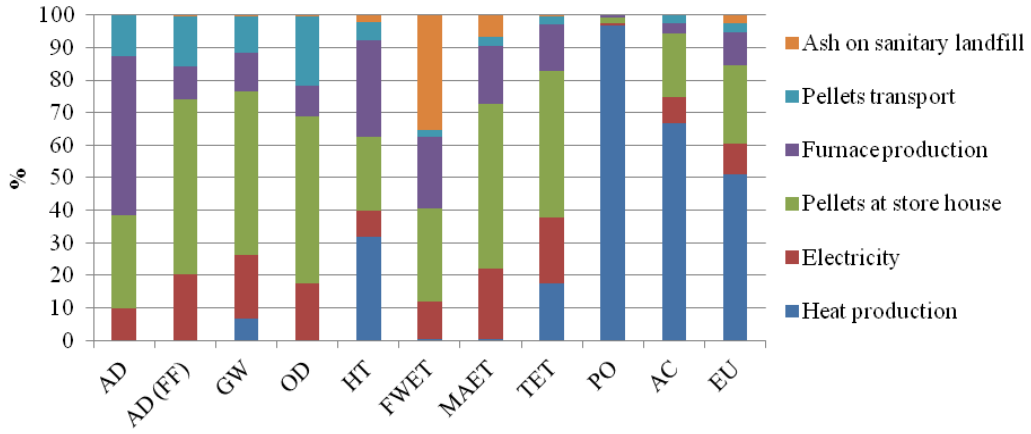


**Fig. 2.** Environmental profile of the functional unit. Method CML-IA (baseline) V 3.04

Acronyms: AD (abiotic depletion); AD(FF) (abiotic depletion (fossil fuels)); GW (global warming (GWP100a)); OD (ozone layer depletion (ODP)); HT (human toxicity); FWET (fresh water aquatic ecotoxicity); MAET (marine aquatic ecotoxicity); TET (terrestrial ecotoxicity); PO (photochemical oxidation); AC (acidification); EU (eutrophication)

| Impact category | Unit | Total | Heat production | Electricity | Pellets at store house | Furnace production | Pellets transport | Ash on sanitary landfill |
|---|---|---|---|---|---|---|---|---|
| AD | kg Sb eq | 2,86E-08 | 0,00E+00 | 2,77E-09 | 8,27E-09 | 1,39E-08 | 3,59E-09 | 4,52E-11 |
| AD (FF) | MJ | 1,37E-01 | 0,00E+00 | 2,77E-02 | 7,39E-02 | 1,36E-02 | 2,12E-02 | 6,48E-04 |
| GW | kg CO2 eq | 1,20E-02 | 8,06E-04 | 2,34E-03 | 6,00E-03 | 1,44E-03 | 1,34E-03 | 4,27E-05 |
| OD | kg CFC-11 eq | 1,17E-09 | 0,00E+00 | 2,04E-10 | 6,01E-10 | 1,14E-10 | 2,46E-10 | 6,79E-12 |
| HT | kg 1,4-DB eq | 7,96E-03 | 2,53E-03 | 6,55E-04 | 1,80E-03 | 2,37E-03 | 4,27E-04 | 1,81E-04 |
| FWET | kg 1,4-DB eq | 4,58E-03 | 1,55E-05 | 5,29E-04 | 1,30E-03 | 1,01E-03 | 1,07E-04 | 1,61E-03 |
| MAET | kg 1,4-DB eq | 1,31E+01 | 6,37E-02 | 2,85E+00 | 6,65E+00 | 2,32E+00 | 3,91E-01 | 8,69E-01 |
| TET | kg 1,4-DB eq | 7,75E-05 | 1,36E-05 | 1,57E-05 | 3,48E-05 | 1,13E-05 | 1,83E-06 | 2,77E-07 |
| PO | kg C2H4 eq | 1,00E-04 | 9,72E-05 | 6,66E-07 | 1,61E-06 | 5,65E-07 | 2,22E-07 | 1,91E-08 |
| AC | kg SO2 eq | 2,01E-04 | 1,34E-04 | 1,64E-05 | 3,90E-05 | 6,91E-06 | 4,42E-06 | 3,53E-07 |
| EU | kg PO4--- eq | 3,16E-05 | 1,61E-05 | 2,94E-06 | 7,63E-06 | 3,18E-06 | 9,72E-07 | 7,55E-07 |

**Table 3.** Process contribution for environmental impacts of the functional unit.

Acronyms: AD (abiotic depletion); AD(FF) (abiotic depletion (fossil fuels)); GW (global warming (GWP100a)); OD (ozone layer depletion (ODP)); HT (human toxicity); FWET (fresh water aquatic ecotoxicity); MAET (marine aquatic ecotoxicity); TET (terrestrial ecotoxicity); PO (photochemical oxidation); AC (acidification); EU (eutrophication).

In Figure 3 and Table 4, the normalized environmental profile of the functional unit is shown. From the environmental point of view, *marine aquatic ecotoxicity* is the most important impact category with $6.78x10^{-14}$ that means the relative contribution of the functional unit in study to a reference situation (World). More than 67% of this impact category is due to electricity, mainly used in the "pellets at store house" (42.4%) and "heat production" (20.2%) processes. "Furnace production" and "ash on sanitary landfill" are others highlighted processes contributing for this impact category with 17.6% and 6.6% respectively.

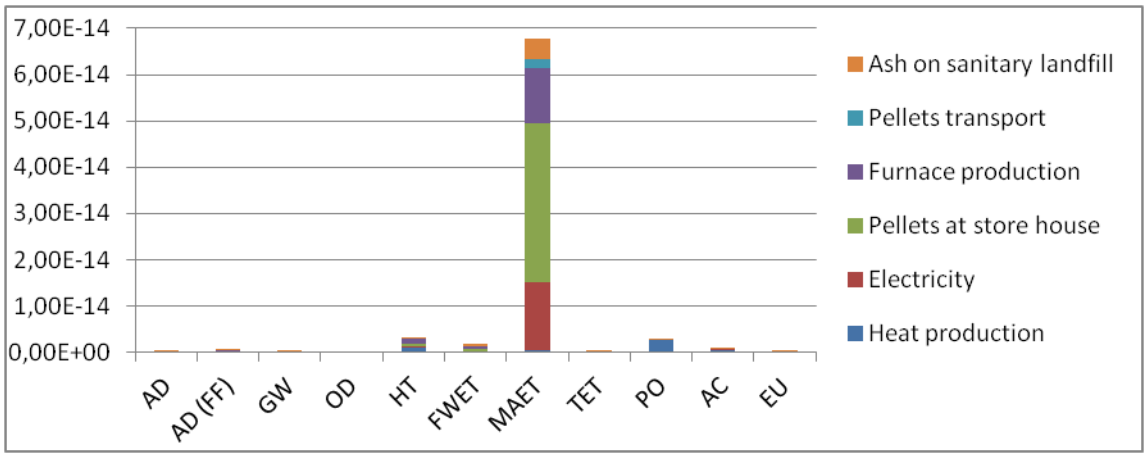


**Fig. 3.** Environmental normalized profile of the functional unit. Method CML-IA (baseline) V 3.04/World 2000/Normalization.

Acronyms: AD (abiotic depletion); AD(FF) (abiotic depletion (fossil fuels)); GW (global warming (GWP100a)); OD (ozone layer depletion (ODP)); HT (human toxicity); FWET (fresh water aquatic ecotoxicity); MAET (marine aquatic ecotoxicity); TET (terrestrial ecotoxicity); PO (photochemical oxidation); AC (acidification); EU (eutrophication)

| Impact category | Unit | Total | Heat production | Electricity | Pellets at store house | Furnace production | Pellets transport | Ash on sanitary landfill |
|---|---|---|---|---|---|---|---|---|
| AD | - | 1,37E-16 | 0,00E+00 | 1,32E-17 | 3,95E-17 | 6,66E-17 | 1,71E-17 | 2,16E-19 |
| AD (FF) | - | 3,60E-16 | 0,00E+00 | 7,29E-17 | 1,94E-16 | 3,58E-17 | 5,56E-17 | 1,70E-18 |
| GW | - | 2,86E-16 | 1,93E-17 | 5,60E-17 | 1,43E-16 | 3,45E-17 | 3,19E-17 | 1,02E-18 |
| OD | - | 5,17E-18 | 0,00E+00 | 9,00E-19 | 2,65E-18 | 5,01E-19 | 1,09E-18 | 2,99E-20 |
| HT | - | 3,09E-15 | 9,82E-16 | 2,54E-16 | 6,97E-16 | 9,19E-16 | 1,66E-16 | 7,04E-17 |
| FWET | - | 1,94E-15 | 6,57E-18 | 2,24E-16 | 5,52E-16 | 4,26E-16 | 4,55E-17 | 6,82E-16 |
| MAET | - | 6,78E-14 | 3,29E-16 | 1,47E-14 | 3,43E-14 | 1,19E-14 | 2,02E-15 | 4,49E-15 |
| TET | - | 7,09E-17 | 1,25E-17 | 1,43E-17 | 3,18E-17 | 1,03E-17 | 1,68E-18 | 2,53E-19 |
| PO | - | 2,73E-15 | 2,64E-15 | 1,81E-17 | 4,38E-17 | 1,54E-17 | 6,05E-18 | 5,18E-19 |
| AC | - | 8,42E-16 | 5,61E-16 | 6,87E-17 | 1,63E-16 | 2,89E-17 | 1,85E-17 | 1,48E-18 |
| EU | - | 2,00E-16 | 1,02E-16 | 1,86E-17 | 4,82E-17 | 2,01E-17 | 6,14E-18 | 4,77E-18 |

**Table 4.** Process contribution for environmental normalized profile of the functional unit (FU).

Acronyms: AD (abiotic depletion); AD(FF) (abiotic depletion (fossil fuels)); GW (global warming (GWP100a)); OD (ozone layer depletion (ODP)); HT (human toxicity); FWET (fresh water aquatic ecotoxicity); MAET (marine aquatic ecotoxicity); TET (terrestrial ecotoxicity); PO (photochemical oxidation); AC (acidification); EU (eutrophication). Unit = contribution of the functional unit to a reference situation (World).

## 4. CONCLUSIONS

The main conclusion of the study is that the hotspots in the heat production from grape stalks pellets are Portuguese electricity used in pellets production process followed by the electricity used in the furnace, furnace production and ash treatment on sanitary landfill. These are hotspots processes ranked according the greatest potential for environmental improvement along the product life cycle.

Other conclusion of the study is that the furnace production is the most important process in terms of abiotic depletion and plays an important role to human toxicity and ecotoxicity (fresh water aquatic, marine aquatic and terrestrial) contradicting the thesis that data from manufacturing of capital goods are, generally, not included in the limits of the system because they have been shown to have a negligible effect on results (Vigon et al. 1992; Frischknecht 1997). Neverthless, this thesis is valid for pellets manufacturing infrastructure that presents marginal results (<0.002%) for all impact categories.

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