Environmental impacts of pellets production from winery residue: a site dependent result?

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Abstract The LCA case study described in this paper deals with the production of pellets from grape marc as fuel for heat generation. Besides heat, the studied system delivers two co-products: grape marc pellets and press juice. The allocation problem has been tackled here using the two different methods of *cut-off* and *system expansion*. The study pointed out that the choice of the method to tackle allocation, as well as of the impact assessment indicators upon which to build the evaluation of different process alternatives, should be made on a site-specific basis. In this case the use of site-specific indicators rather than global ones can vary the alternatives' ranking. The study highlighted the importance of embedding the consideration of regional specificities, infrastructures, social and economic aspects in the overall evaluation of the "best" trade-off strategy for heat production from grape marc pellets.

1 Introduction

Life Cycle Assessment (LCA) literature differentiates between site-generic, site-dependent, and site specific characterization factors [1]. In site-generic modelling all sources of pollutant emissions are considered to contribute to the same generic receiving environment. Site-generic factors are applied over large geographic regions, such as continents or the whole globe. In site-dependent modelling some spatial differentiation is performed by distinguishing between classes of sources and considering a specific receiving environment. Site-dependent characterization factors can follow country or state boundaries.

In site-specific modelling a very detailed spatial differentiation is performed by considering sources at specific locations. Site-specific modelling allows large accuracy in modelling of the impact at individual location in the sorrounding of the source, such as a particular factory or landfill. This typically involves local knowledge about conditions of specific ecosystems exposed to the emissions.

To date, in most of the LCA studies the impact categories are not always selected by LCA analysts on the basis of the actual effects of the studied production process on the local scale. As a consequence, if spatial differentiation in the choice of indicators (and, if possible, also characterization factors) is not applied, the Life Cycle Impact Assessment (LCIA) is typically not site-specific and only sometimes site-dependent.

It has already been proved that the inclusion of site-specific data in the life-cycle inventory enhances the utility and reliability of conclusions drawn from LCA results [2]. For impact categories that are not global in nature such as acidification, eutrophication, or toxicity, the use of generic data can lead to results that under- or overestimate the impacts with respect to the local specificities. Clearly, the need for spatial differentiation depends on the scope and boundaries of the study. However, when assessing LCIs from different regions, or when geographical conditions of the emission location are known, regionalization might increase the discriminating power of LCIA [3].

Several authors have proposed methods for regionalized LCA [3-5]. An interesting example of regionalization in LCA is provided in [6], where the authors quantify the environmental impacts of freshwater use in vegetable and fruit production. In [7] a method (the *Water Stress Index*) for assessing the environmental impacts of freshwater consumption is presented. The method also takes into consideration temporal variability of water availability in order to account for increased impacts in specific periods characterized by larger water scarcity.

Although this study does not reach the level of detail of a regionalised LCIA, it supports the evidence that when the choice of the impact categories (and related indicators) upon which to base the comparison among different operational alternatives is guided by a specific knowledge of the local environment, the results of the assessment are expected to be more meaningful.

If, for example, one wants to compare two alternative ways of bottling milk in a certain region which particularly suffers from problems related to the presence of acid rains, then in the weighting phase of LCIA a higher weight should probably be assigned to the category "acidification, eutrophication", rather than other categories such as "climate change"; toxic effects on humans and ecosystems (including ozone formation); or depletion of fossil fuels and minerals.

2 Case study

The LCA case study described in the paper deals with the production of pellets from grape marc and their combustion to generate heat. LCI data have been obtained from extensive tests at the field scale and using data collected at the company RLP Agroscience GmbH (Neustadt a.d. Weinstraße, Germany). The study was carried out within the project MARC (*Energy recovery of biodegradable waste streams from wine production*), financed by the Ministry of Culture, Education and Research (Ministère de la Culture, de l'Enseignement Supérieur et de la Recherche - MCESR), the Ministry of Environment (Ministère de l'Environnement - MEV) and the Viticulture Institute (Institut Viti-Vinicole - IVV) of Luxembourg.

The study aimed at highlighting the environmental hot spots in the production cycle of pellets and heat and to assess the competitiveness (from an environmental standpoint) of marc pellets with respect to common energy carriers for heat production (such as natural gas, light oil and wood chips). The chosen functional unit is the production of 1MJ of heat from the combustion of CEN TS 14961 [8] compliant pellets produced from fresh grape marc.

The studied system includes seven main process steps: (1) Transport of fresh grape marc from winery to the factory site & biomass storage; (2) Mechanical dehydration; (3) Thermal drying; (4) Milling; (5) Pelletisation; (6) Cooling; (7) Transport of pellets to the furnace and combustion.

An important assumption concerns the origin of the main raw material: the fresh grape marc. In this study, the fresh grape marc was considered as an organic waste resulting from the production of wine. Thus, no environmental burdens due to its production were taken into account.

The studied system delivers three products: (1) heat coming from pellets combustion, (2) press juice produced during the dehydration phase of fresh grape marc and (3) ashes coming from the combustion of pellets.

The approaches chosen to deal with this multi-functionality problem are: the *cut-off approach*, limiting the scope of the inquiry to the main product (i.e. the heat) and the *system expansion approach*, where the system's boundaries are enlarged in order to take into account the positive and negative impacts linked to the fate of the co-products (press juice and ashes). The system boundaries in the two cases are schematized in Fig. 1.

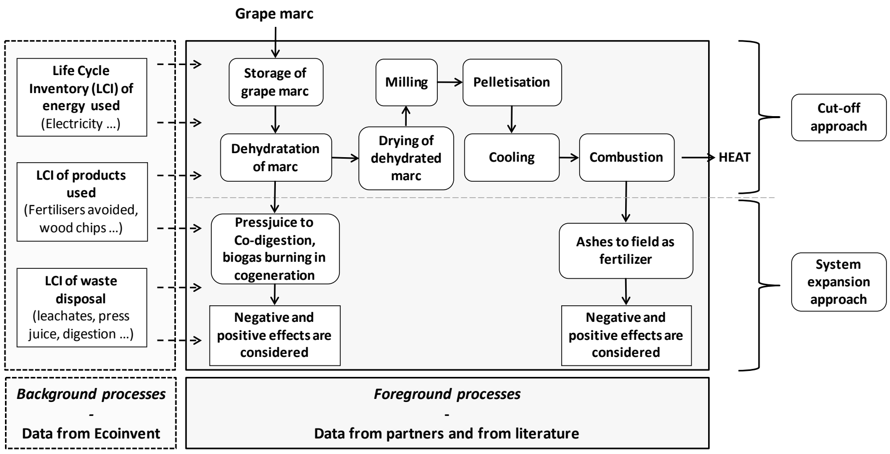

Fig. 1: **System boundaries of heat production from grape marc pellets in the two modelling approaches (cut-off and system expansion).**

According to the average data from Agroscience, the normal water content for a representative mix of different kinds of fresh grape marc amounts to about 68.6% of the total mass. Before entering the drying phase, the fresh marc undergoes a mechanical dehydratation phase, which decreases its water content to about 55%. During this phase a significant amount of press juice is produced, which is then sent to an anaerobic digester to produce biogas.

The objective of the next phase, the drying phase, is to increase the dry matter content up to about 88%; this is necessary for the pelletisation process. Different systems can be used to dry the marc. The scenario called *baseline scenario* uses a belt dryer fuelled with the heat produced by burning the same pellets coming from grape marc. Three alternative scenarios were then assessed in the study. Two of them are based on the utilization of belts dryers respectively fuelled with wood chips and natural gas, and a last alternative considers the utilization of an electrical dryer with a recirculation of air.

After the drying phase, in order to homogenise the dried grape marc, a milling step is necessary before entering the pelletisation process. The dried and homogenised grape marc is finally pelletised in order to obtain the final product, i.e. the grape marc pellets. Finally, in order to gain the required stability of pellets grains, they are cooled down in a climatic chamber maintained at 20°C for several days with humidity regulation.

The final combustion of the grape marc pellets in appropriate furnaces leads to the use of electricity and the production of useable heat, along with gaseous emissions and ashes. The fate of the dry matter losses from the milling and pellettisation phase are not specified in our model of the system. Concerning the fate of the

press juice and ashes, in the system expansion scenario we assumed that the press juice is digested in a co-fermentation plant (processing biowaste and slurry) to produce biogas and that the ashes are used as a surrogate of fertilizers for soil amendment. It is assumed that the press juice replaces 10% of the slurry in the digester, since they have very similar properties. Nevertheless, the proportion of methane in the total biogas production is adapted according to the productivity of press juice and its content of methane. The biogas is then burned in a combined heat and power plant (CHP), thus producing electricity and heat. The multi-functionality problem in the cogeneration process has been treated using an allocation based on the exergy content of the co-products. The main assumption made at this stage is that both electricity and heat produced will be totally reused, thus avoiding their stand-alone production. However, even though this assumption is realistic in the case of electricity, it is not so for the heat. The local reuse of this latter depends in fact on many factors. The portion of heat that can be reused (and the corresponding avoided burdens from a stand-alone heat production process) varies depending for instance on the location of the cogeneration plant (proximity or not of a urban agglomerate or an industry), the final use of the heat produced (for heating swimming pools or dwellings, or for industrial applications), the geographical position of the plant (which influences the seasonal mean outdoor temperature), the period of the year (summer or winter), the heat market value, etc. Part of the electricity and heat is reused in the digester to pre-heat the press juice. In the baseline scenario, the net production of electricity and heat (after subtracting the amounts of electricity and heat internally used for the digestion of the press juice) is respectively 0.196 kWh and 0.58 MJ for each kg of press juice produced.
In the *cut-off* approach, the press juice is considered as a neutral product, thus it leaves the system of pellets production and disappears from the boundaries of the studied system. In this case, neither positive (i.e. avoided) nor negative impacts are associated to the disposal/reuse of press juice. This is indeed a worst case scenario and is linked to numerous uncertainties that can significantly affect the results.

2.1 Life Cycle Impact Assessment (LCIA)

The impact assessment method applied in this study is the ReCiPe1.04 [9]. Four midpoint impact categories were taken into account in our study because we deemed them very relevant for the kind of system investigated:
1) *Climate change*, because of the release of CO_2 during combustion;

2) *Particulate matter formation*, because of the release of particulates and NOx during combustion;
3) *Terrestrial ecotoxicity*, because of the disposal of ashes on land when applying the system expansion approach;
4) *Fossil resources depletion*, because of the energy consumption, especially in the drying phase of grape marc.
Along with them, the comparison among the analyzed scenarios has also been based on the following impacts, since they appeared particularly high in comparison to other impacts, after applying normalization:
5) *Human toxicity*;
6) *Marine ecotoxicity*;
7) *Freshwater eutrophication*;
8) *Natural land transformation*.
Finally, two additional impact indicators (*photochemical ozone formation* and *marine water eutrophication*) were calculated, since they are recommended in [9] among the midpoint indicators.
As it can be observed in Fig. 2 (which refers to the baseline scenario), the impacts of the production of heat from grape marc pellets are mainly generated by the drying process (30% to 40% of the total) and the combustion of pellets (30% to 70% of the total).

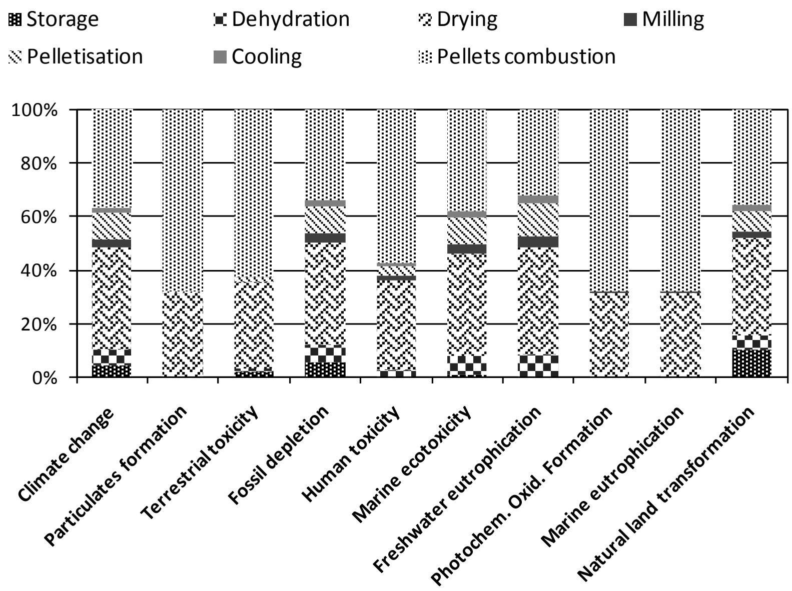

Fig. 2: Contribution analysis to different impact categories for the baseline scenario (cut-off approach).

The remaining part of the paper will be devoted to a sensitivity analysis focused on the parameters influencing the choice among different operational scenarios.

2.2 Sensitivity analysis

This analysis allows to pinpoint the parts of the life cycle which contribute the most to the different impact categories and thus to determine the hot spots where some strategic choices have to be made to improve the environmental performances of the system. This analysis also allows an evaluation of the changes in the results induced by relevant changes in the assumptions made.
The sensitivity on results of the following parameters and assumptions have been observed:

- the technology used to produce heat during the drying phase;
- the approach applied to manage the co-product issue, cut-off vs. system expansion;
- the influence of the heat recovery ratio after burning biogas;
- the water content of fresh grape marc in both approaches.

Three alternatives sources have been considered for the heat production: (1) Wood chips, (2) Natural Gas and (3) Electricity.
When all the impact categories listed in section 2.1 are considered, the performances of the different alternatives do not exhibit the same trend across all the indicators. The multi-criteria optimization problem has thus no dominant solution, and the choice of the "best" alternative depends on the set of impact indicators selected. A possibility to help the decision making is to limit the choice to only a few impacts that are considered particularly important like, for instance, the human toxicity, the climate change and the freshwater ecotoxicity.
In so doing, we found out that the scenario with wood chips is in two instances (climate change and freshwater ecotoxicity) the best performing one, as showed in Tab. 1, which lists the results obtained for each category as percentage with respect to the worst score obtained in each impact category (marked as 100%).

Tab. 1: Comparison of different drying alternatives considering three impact categories and using the cut-off approach.

	Baseline	Wood chips	Electricity	Natural Gas
Climate Change	41%	31%	64%	100%
Human Toxicity	91%	100%	95%	69%
Freshwater Ecotox.	55%	43%	100%	47%

Of course, the choice of the relevant indicators would be here more meaningful if carried out on the basis of the specific knowledge of the most vulnerable local aspects. In this case the use of site-specific indicators (such as freshwater ecotoxicity) rather than global ones (such as climate change) can vary the alternatives' ranking.
Ranking the impact categories on the bases of the normalised impact scores, the four impact categories showed in Tab. 2 have been identified as the most relevant ones. Results reported in Tab. 2 are expressed again as percentage with respect to the worst case, marked as 100%.

Tab. 2: Comparison of different drying alternatives considering the four impact categories with the highest scores after normalization.

	Baseline	Wood chips	Electricity	Natural Gas
Human Toxicity	91%	100%	95%	69%
Marine Ecotox.	62%	54%	100%	55%
Freshwater Eutroph.	55%	43%	100%	47%
Natural land transform.	33%	34%	46%	100%

In this case the choice of the environmentally "most competitive" alternative is more difficult, as wood chips, baseline and natural gas, all have the best scores at least in one of the impact categories. Since the wood chips alternative scores best twice, it is probably still the alternative to be preferred.
Concerning the utilization of the heat produced in the CHP plant, as we discussed above, the utilization outside of the plant of the total amount of heat produced is not very realistic. A more realistic possibility would be the production of pellets and combustion of biogas on the same place, thus allowing the utilization of the heat produced by biogas for drying pellets. This would make the hypotesis of full utilization of the heat more realistic and would make the final use of the heat less dependent on the local features of the receiving context (the users). Figure 3 shows the impacts related to this scenario and to the (unrealistic) scenario of 100% utilization of the heat outside of the plant (remote heating systems, etc).
Besides the considerations already made about the two co-products electricity and heat, analogue considerations about the importance of regional specificities can be made concerning the ashes coming from the combustion of pellets. In fact, the utilization of ash for soil amendment in cultivation processes is only possible if the concentration of pollutants such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons and heavy metals is below the level permitted by the legal requirements. This depends on the physical-chemical parameters of the soil in the interested region and on its proximity to vulnerable targets such as water bodies. If

local conditions do not allow this utilization, then a different end-of-life scenario has to be conceived for the ashes and they might actually be considered as waste.

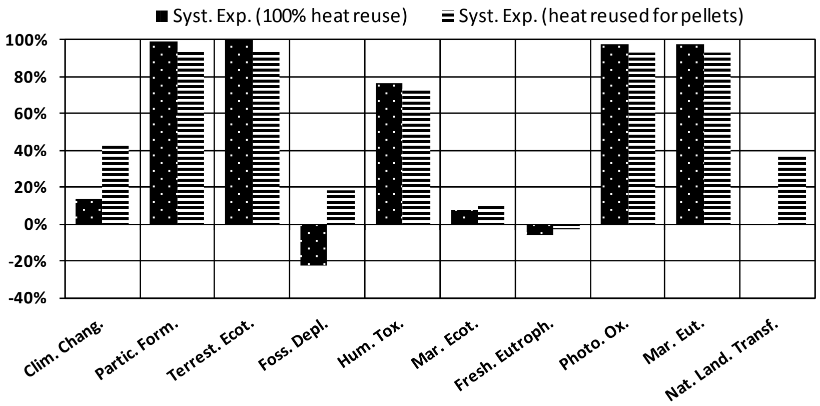

Fig. 3: Comparison of the two scenarios of the system expansion approach considering a full valorisation of the excess heat of cogeneration: (1) 100% reuse leading to avoided impacts from an equivalent stand-alone heat production process; (2) 100% reuse leading to reducing combustion of pellets from marc for the drying step.

A last important variable to carefully take into account is the water content in the fresh grape marc. In fact, together with the performance of the dehydration technique used, the water content of the marc influences the amount of energy needed for the drying phase. In fact, the higher the efficiency of the mechanical dehydration phase (e.g. bringing the water mass content from 70% to 50%), the higher the quantity of press juice obtained and the lower the amount of heat needed for the subsequent drying step of the dehydrated marc (which brings the water content from 50% to about 18%). The measured water content of fresh grape marc varied from about 52% to 71%. In the sensitivity analysis we made this parameter vary from 50% to 75%.

While in the cut-off approach the water content monotonically influences the impacts in each and every impact category (the higher the water content the higher the impact), in the system expansion approach the situation turned out to be different. In particular, for some impact categories (particulate matter formation, terrestrial ecotoxicity, photochemical oxidant formation, marine eutrophication, natural land transformation) the trend of the impacts as a function of the water content is the same as in the cut-off approach. For other impact categories (freshwater eutrophication) the trend is opposite (the higher the water content the lower the impact). Finally, there are other impact categories (climate change, fossil depletion, human toxicity, marine ecotoxicity) which exibit a threshold effect: the impacts decrease until a certain water content (approximately 65% to 70%) and then increase again.

A final important consideration has to be done concerning the comparison of the environmental impacts of the heat produced from grape marc pellets with respect to heat produced with other fuels. The analysis carried out showed that the approach considered to treat the multi-functionality issue significantly influences the results. Heat produced from grape marc pellets is far more competitive with respect to the other alternatives when considering the system expansion approach than the cut-off approach.

Table 3 shows the comparison between the evaluated alternatives, based on the impact categories where at least one scenario has a normalised result significantly higher than 1E-5 point (European equivalent pollution). The results are again expressed in percentage with respect to the worst case, marked as 100%. It can be observed that there is no clear dominant alternative.

Tab. 3: Comparison of environmental impacts of heat production from pellets with other energy sources on the basis of six impact categories, considering the system expansion approach and applying ReCiPe1.04.

	Baseline	Natural gas	Light fuel oil	Mixed chips
Human Toxicity	42%	8%	12%	100%
Marine Ecotox.	100%	59%	76%	71%
Fossil Depletion	14%	97%	100%	5%
Terrestrial Ecotox.	1%	0%	1%	100%
Freshwater Eutroph.	100%	44%	39%	49%
Natural land transform.	7%	48%	100%	27%

When communicating the results of the assessment, it is thus very important to precise which approach has been chosen. However, independently of the variation of results according to the approach used, it is not easy to express a clear preference judgement between the different fuels since they all outperform each other in some of the impact categories. Once again, the choice of the indicators upon which to base the assessment depends more on political targets of reduction of certain impact categories than on a strong, clear and absolute preference from the LCA point of view.

3 Conclusions

The paper describes the main results of the LCA study of a process of production of pellets from grape marc and their combustion to produce heat.
The problem at hand involved several assumptions and left the field open for a complete environmental assessment of different alternatives based on: 1) the technology considered for producing heat during the drying phase; 2) the approach applied to deal with the co-product issue (cut-off vs. system expansion); 3) the heat recovery ratio after burning biogas (i.e. the percentage of this heat that is assumed to be used outside of the plant, so that avoided burdends from an equivalent stand-alone heat production process can be accounted for); 4) the water mass content of fresh grape marc.
It was thus a multi-criteria optimization problem with no dominant solution. In our research we point out how the choice of the “best” alternative significantly depends on the set of impact indicators selected to conduct the assessment. In our case the use of local, site-specific indicators, rather than global ones, varies the alternatives’ ranking. The choice of these indicators should be based on the knowledge of the specific features of the local territory (e.g. possible uses of the excess heat; particular vulnerabilities of the local territory in some specific aspects; etc.) in order to make the results reached (as well as the conclusion drawn and the decisons taken) more meaningful and scientifically based.
In conlclusion, the study suggests that the strategy for the overall evaluation of heat production from grape marc pellets in the factory at hand, should involve not only the current handling of grape marc in Neustadt a.d. Weinstraße and the Greater Region and its global environmental impacts, but also the regional specificities concerning local vulnerabilities, infrastructures, final users, social and economic (marketal) aspects.

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