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Véronique Bellon Maurel, G. Peters, S. Clermidy, G. Frizarin, G. Sinfort, H. Ojeda, P. Roux, M.D. Short

### ► To cite this version:

Véronique Bellon Maurel, G. Peters, S. Clermidy, G. Frizarin, G. Sinfort, et al.. Streamlining life cycle inventory data generation in agriculture using traceability data and information and communication technologies: part II. Application to viticulture. *Journal of Cleaner Production*, 2015, 87, pp.119-129. 10.1016/j.jclepro.2014.09.095 . hal-01469261

**HAL Id: hal-01469261**

**<https://hal.science/hal-01469261>**

Submitted on 16 Feb 2017

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1 **Streamlining life cycle inventory data generation in agriculture using**  
2 **traceability data and information and communication technologies – Part II:**  
3 **Application to viticulture**

4 *Véronique Bellon-Maurel<sup>a\*</sup>, Gregory M. Peters<sup>b,c</sup>, Sonia Clermidy<sup>a</sup>, Gustavo Frizarin<sup>d</sup>, Carole*  
5 *Sinfort<sup>d</sup>, Hernan Ojeda<sup>e</sup>, Philippe Roux<sup>a</sup>, Michael D. Short<sup>b,f</sup>*

a- Irstea-Montpellier Supagro - UMR ITAP, ELSA Group, BP5095, 34033 Montpellier cedex 1,  
France, e-mail: [veronique.bellon@irstea.fr](mailto:veronique.bellon@irstea.fr), Ph : + 33 4 67 04 63 19; Fax: + 33 4 67 04 63 06, e-  
mail : [philippe.roux@irstea.fr](mailto:philippe.roux@irstea.fr)

b- UNSW Water Research Centre, School of Civil and Environmental Engineering, University of  
New South Wales, Sydney, New South Wales 2052, Australia,

c- Chemical and Biochemical Engineering, Chalmers University of Technology, 41296  
Gothenburg, Sweden, e-mail: [petersg@chalmers.se](mailto:petersg@chalmers.se), Ph : +46 31 772 30 03, Fax : +46 31 772  
2995

d- Montpellier Supagro – Irstea - UMR ITAP, ELSA Group, 2 place Viala, 34000 Montpellier  
France, e-mail : [sinfort@supagro.inra.fr](mailto:sinfort@supagro.inra.fr), Ph : + 33 4 99 61 23 24; Fax: + 33 4 67 04 63 06

e- INRA - UE999 Pech Rouge, F-11430 GRUISSAN, France, e-mail: [ojeda@supagro.inra.fr](mailto:ojeda@supagro.inra.fr), Ph:  
+33 (0) 4 68 49 44 08; Fax 04 68 49 44 02

f- Centre for Water Management and Reuse, School of Natural and Built Environments,  
University of South Australia, Adelaide, South Australia 5095, Australia, e-mail:  
[michael.short@unisa.edu.au](mailto:michael.short@unisa.edu.au), Ph: +61 8 8302 3496

6 **\* corresponding author.**

7 **ABSTRACT**

8 Agricultural systems are increasingly subjected to environmental life cycle assessment (LCA) but  
9 generating life cycle inventory (LCI) data in agriculture remains a challenge. In Part I, it was  
10 suggested that traceability data are a good basis for generating precise LCI with reduced effort,  
11 especially when collected by efficient information and communication technologies (ICTs). The  
12 aim of this paper is to demonstrate this for wine grape production and generate a list of data to be  
13 collected for streamlined LCI generation. The study is carried out in the South of France, on a  
14 viticultural farm implementing electronic traceability of each cultivation operation, i.e. tillage,  
15 fertilisation, crop protection, weeding, canopy management and harvesting (no irrigation is  
16 needed at this vineyard). For each operation, specific emission models which satisfy the trade-off  
17 between accuracy and need for data have been identified. Traceability data must be supplemented  
18 with data related to the plot, equipment and inputs to feed the models. The sensitivity of the LCA  
19 outputs to plot soil type and year of cultivation was studied. Consistent with previous agricultural  
20 studies, the results show that operations such as pesticide spraying and fertilising have large  
21 environmental impacts in this Mediterranean vineyard. Notable variations occur in life cycle  
22 impact assessment indicators, principally due to variations in crop yield; however, the influence  
23 of secondary factors such as soil type and agricultural practices is also evident and this  
24 contribution allows us to better characterise the variability of grape production and to show that  
25 streamlined LCI can be created using traceability data. Ultimately, this paper delivers two results.  
26 It provides simple models, and relevant data and methodology to enable viticultural LCAs to be  
27 undertaken. Additionally, it demonstrates that accurate LCIs can be built based on data already  
28 collected for traceability when supplemented with other easily collectable data (weather and farm  
29 structural data). Overall, this work paves the way for streamlined LCI in agriculture.

30 **Keywords:** Grape, life cycle inventory, traceability, LCA, agriculture, data

31 **1. Introduction.**

32 In a first paper (Bellon-Maurel *et al.*, 2014), several approaches were presented for streamlining  
33 life cycle inventory (LCI) data generation in agriculture and therein a new approach, called the  
34 “traceability” approach was advocated, in which “traceability data” and, where possible, data  
35 collected by information and communication technologies (ICTs), are used to generate LCI data.  
36 Traceability is defined as “all compulsory or voluntary on-farm records”. The aim of this second  
37 paper is to demonstrate that traceability data are a good basis for generating LCIs in viticulture,  
38 provided that appropriate emission models are used and that certain additional data are available.  
39 To achieve this, a life cycle assessment (LCA) is performed on a case study vineyard in southern  
40 France using data from cultivation registers. Viticulture was chosen because emissions can be  
41 very site-specific and grapevines are grown worldwide in diverse climates using a large range of  
42 techniques. Moreover, few LCAs of viticultural systems exist in the literature (Aranda *et al.*,  
43 2005; Pizzigallo *et al.*, 2008; Gazulla *et al.*, 2010; Vázquez-Rowe *et al.*, 2012).

44  
45 In France, the requirements for traceability in viticulture include 19 documents, with information  
46 on the farm (crop rotation, vineyard setting, etc.) and on operations (fertilisation, crop protection,  
47 irrigation, harvesting) (Abt *et al.*, 2007). Traceability data can, therefore, cover a broad range of  
48 viticultural operations; however, using such data for LCI generation is not straightforward, as it is  
49 expressed in units related to the agricultural activities (e.g., fertiliser type and quantity) rather  
50 than units of emitted substances. Emissions may be computed by using emission factors attached  
51 to activities based on international LCA databases such as Ecoinvent. A more accurate alternative  
52 is to use local emission models, but this requires additional data (Poppe and Meeusen, 2000). In  
53 agriculture, such data can be classified as:

- 54 - “Structural data” about production methods (e.g., plot size, grape variety, slope, soil type
- 55 and machinery);
- 56 - “Activity data” related to the agricultural operations;
- 57 - “Weather data” which are easily obtained from meteorological stations.

58 The objective of this paper is to demonstrate that the use of traceability data for LCI generation  
59 provides accurate results with minimal effort and is a sound approach for streamlining LCA in  
60 agriculture. After introducing the case study system, the paper describes the LCI generation phase  
61 wherein emission sources in the grape production system are identified and linked to simple  
62 emission models, followed by a description of which data must be recorded to compute these  
63 emissions. A LCA is then performed with regard to grape production and a sensitivity analysis  
64 undertaken to test the robustness of results relative to production year and soil type. The outputs  
65 of the paper are: a specification sheet for building a LCA-ready traceability database from data  
66 already recorded in viticultural traceability systems; and a full LCA of wine grape production  
67 validating the traceability-derived LCI approach.

## 68 **2. Case study description and modelling approach**

### 69 2.1 LCA methodology

70 Established LCA methodology, more thoroughly described in Part I is followed: first, the goal  
71 and scope of the study are defined; second, the LCI is constructed; third, the impacts and  
72 damages are computed from the inventory via well-known life cycle impact assessment (LCIA)  
73 methods; finally, data are interpreted and a sensitivity analysis performed (ISO, 2006). The LCA  
74 software SimaPro 7.3.3 (PRé Consultants, NL) was used and the LCIA undertaken using ReCiPe  
75 Midpoint (H) 1.07 ‘hierarchist’ consensus model. The H (hierarchical) method is considered the  
76 default model and represents a compromise between the ‘individualist’ approach (which uses

77 only proven cause–effect relations in a short-term techno-centric perspective) and the  
78 ‘egalitarian’ method (which is based on the precautionary principle and adopts a longer-term  
79 perspective). Ecoinvent v2.2 (Swiss Centre for Life Cycle Inventories at [www.ecoinvent.ch](http://www.ecoinvent.ch)) was  
80 used to find LCI data for background processes, but for the foreground processes specific to  
81 viticulture, emissions/consumptions were computed based on models of each operation.

82

## 83 2.2 Goal and scope

84 The case study system is one of wine grape production from an experimental 100-plot vineyard  
85 owned by INRA in the south of France, where a Mediterranean climate prevails (Pech-Rouge,  
86 Gruissan). The cradle-to-farm gate LCA case study describes the production of 1 kg of grapes  
87 (functional unit) of one variety (Syrah) in five case study configurations representing variable  
88 conditions: three plots (P 22, P 80 and P103) are selected in three different zones to demonstrate  
89 the influence of different soil properties. Additionally, one plot (P80) is studied in different years  
90 (2004, 2006 and 2008) to examine temporal variability. The geographic boundaries of the study  
91 are those of the farm; the transfers from the farm buildings to the plots are not taken into account  
92 except for the grape harvesting, as transfers can be numerous. The construction of farm  
93 machinery is taken into account, based on the Ecoinvent database. The vineyard plantation and  
94 setting phases have not been taken into account, as one of the main objectives of this study is to  
95 carry out a sensitivity analysis with regard to the variation of soil and year conditions, for which  
96 the plantation phase is of no use. Moreover, the planting / setting phase is only three years out of  
97 at least 30 year lifespan for these vineyards (30-60 years) which is a reason why some authors  
98 have also excluded it (e.g. Gazulla *et al.*, 2010). Other researchers have shown that for 30-year  
99 vines, the planting / setting phases could contribute to 10-15% of the impacts due for fuel,  
100 equipment and fertilizers (Pizzigallo *et al.*, 2008).

101 The time span of each LCA is one year (starting in September). The viticultural operations can be  
102 organised into the following operation classes: tillage (for any soil management operation);  
103 operations on the canopy (trimming, pruning, etc.); pesticide spraying; fertilising; and grape  
104 harvesting.

105

### 106 2.3 From traceability and additional data to LCI

107 The INRA viticultural property is equipped with a traceability system named Agreo (Maferme-  
108 Neotic, France). Agreo is a computer tool for technical management of agricultural and agro-  
109 industrial production which facilitates traceability data capture. This software is presently used on  
110 a computer, but it is also available for smartphones. The operator enters data about operations he  
111 has carried out on the farm. At the end of the season, Agreo provides tables for each plot with  
112 various pieces of information, relative to the date of the operation, the input nature and doses, as  
113 well as harvested quantities. As an example, Table 1 shows data for one plot (P80, year 2006)  
114 used in this LCA.

115

116 Daily weather data (temperature, rainfall, evapotranspiration (ETP) etc.) obtained from INRA  
117 weather stations is also available. In addition to these variables, so-called “structural” data  
118 relative to the farm are also recorded and used: density of vine stocks on each plot; inter-row  
119 distance; soil properties; type of machinery; name of fertilisers and pesticides. Data relative to the  
120 plots are described in Table 2 and basic grape growing operational inventory data are summarised  
121 in Table 3. Based on data reported in these tables and on appropriate models, LCI is computed.

122

### 123 **3. Material and methods: Life cycle inventory**

124 As stated above, LCI are computed for all background processes (i.e. equipment manufacturing,  
125 input production) using Ecoinvent, whereas LCI related to foreground processes (e.g., equipment  
126 use, resource inputs) are computed based on emission models. To demonstrate the process, a  
127 typical example (i.e. nitrogen emissions) is given below to describe the step-by-step procedure in  
128 which traceability and additional data are converted to functional LCI (a more detailed  
129 description of this approach is given in the Supplementary data S1).

130

### 131 3.1. Emissions from equipment use

132 Emissions from equipment use are generated during operations (energy consumption, soil  
133 compaction, etc.) or “embodied” in equipment (from manufacturing). As detailed earlier, only  
134 emissions from equipment operations are considered in the foreground. There are limited data on  
135 energy use in viticultural operations. Fuel consumption depends first on the operation carried out,  
136 but is also sensitive to operating conditions (Gaviglio *et al.*, 2009), with vehicle and engine speed  
137 having the largest effect. A moderate slope increases tractor fuel consumption by around 10% or  
138 more when a tool is attached. Air conditioning increases consumption by 10–15%. Using 4WD  
139 has no measurable effect on fuel consumption. For tillage emissions, both the tillage depth and  
140 soil moisture content impact fuel consumption rates. Table 4 gives average fuel consumption data  
141 for each operation, and its sensitivity to vehicle speed and engine speed (i.e. to setting a lower  
142 speed of universal joint shaft).

143

144 In addition to emissions related to energy use, emissions may also occur from soil compaction by  
145 the machinery. Soil compaction is the process in which a stress applied to a soil causes  
146 densification. But this phenomenon appears moderate in viticulture (Van Dijck and Van Asch,  
147 2002; Lagacherie *et al.*, 2006) and is, therefore, excluded here. Accordingly, the most important



148 vehicle data to be recorded for LCI are hours of use for each operation and tillage depth. The  
149 average vehicle speed and plot conditions (i.e. plot slope, which increases consumption after  
150 (Gaviglio *et al.*, 2009)) could be recorded as secondary input variables.

151  
152 3.2 Tillage and cover crops  
153 Tillage may influence both CO<sub>2</sub> and N<sub>2</sub>O emissions, but the phenomena are complex and the  
154 literature reflects diverging conclusions. Comparisons of cultivated versus cover-cropped  
155 vineyards have shown that the latter generates less N<sub>2</sub>O by reducing denitrification (Steenwerth  
156 and Belina, 2008; Lee *et al.*, 2009). Steenwerth et al (2010) suggest that soil CO<sub>2</sub> emissions in  
157 vineyard are primarily controlled by soil water content in summer and soil temperature in winter,  
158 rather than by soil management techniques. Ploughing depth may also induce CO<sub>2</sub> release  
159 (Reicosky and Archer, 2007) as well as increasing fuel consumption. Therefore and as outlined  
160 above, the type of tillage (i.e. surface or deep) has been recorded.

161  
162 3.3 Irrigation  
163 Three types of irrigation systems are commonly used in viticulture: surface irrigation; sprinkler;  
164 and micro-irrigation (Prichard, 2000). Emissions and resource consumption linked to irrigation  
165 are: (i) direct emissions relating to infrastructure, pumping energy consumption (which is linked  
166 to the pumped volume, delivery pressure and water table depth) and direct water consumption  
167 (Bayart *et al.*, 2010; Nunez *et al.*, 2010; Peters *et al.*, 2010); and (ii) indirect emissions such as  
168 leaching (fertilisers, pesticides), salinisation and N<sub>2</sub>O emissions from water-saturated areas.  
169 Accordingly, data to be recorded are the amount of consumed water, average water depth and  
170 type of irrigation system.

171

## 172 3.4 Fertilisation

173 Viticultural macronutrient demand (N, P, K, Mg, Ca) is lower than that of annual crops (Biala,  
174 2000; Guilbaut, 2006) but still relevant to eutrophication and soil acidification indicators in LCA.  
175 The fates of these nutrients depends to a large extent on soil properties, on the natural levels of  
176 these nutrients (Mercik *et al.*, 2000) and on conditions of application (Powers, 2007; Langevin *et*  
177 *al.*, 2010; Peters *et al.*, 2011a). As N emissions are very difficult to model, a simple methodology  
178 is introduced below that allows viticultural N emissions to be estimated from readily available  
179 data.

### 180 3.4.1 Nitrogen

181 Numerous models are available for computing N emissions; Cannavo *et al.* (2008) reviewed 62 of  
182 them and recently an integrated model for computing all N emission was introduced (Parnaudeau  
183 *et al.*, 2012). Most models have two drawbacks: first, they generally deal with cereals; second,  
184 they require data that are difficult to obtain. In line with previous authors who have developed  
185 heuristic approaches for streamlining N emissions computation for LCA (Brentrup *et al.*, 2000),  
186 N emissions are estimated here using simple and sometimes empirical models based on a  
187 restricted number of parameters. Our approach to N emission computation is based on the  
188 following assumptions and parameters:

- 189 -  $\text{NH}_3$  volatilisation occurs first, i.e. during or just after application (Sommer and  
190 Hutchings, 2001);
- 191 -  $\text{N}_2\text{O}$  emissions are computed after Brentrup *et al.* (2000) using IPCC emission factors for  
192 land-applied N after correction for volatilised  $\text{NH}_3$ ;
- 193 -  $\text{NO}_3^-$  leaching can be computed from the nitrogen budget, after  $\text{NH}_3$  and  $\text{N}_2\text{O}$  emissions  
194 have been removed (Kücke and Kleeberg, 1997; Brentrup *et al.*, 2000). In our approach,

195 and unlike that of Brentup et al (2000) who worked on an annual time basis, this budget is  
196 computed on a monthly basis, since rainfall data are daily and plant N uptake is modeled  
197 on a monthly basis.

198  
199 As detailed earlier, volatilisation ( $\text{NH}_3$  emission) peaks shortly after application and then quickly  
200 declines. Accordingly, our approach assumes that volatilised N derives only from the initial  $\text{NH}_4^+$   
201 input following the function:

202

$$203 \quad N_{vol} = N_{\text{NH}_4^+} \times C_v$$

204 where  $N_{\text{NH}_4^+}$  is the amount of  $\text{NH}_4^+$  in the fertiliser input and  $C_v$  is the volatilisation coefficient.

205

206 The volatilisation coefficient ( $C_v$ ) depends on the type of input. It is considered that  $\text{NH}_4^+$   
207 follows an exponential decay profile with a half-life of 12 hours. If rain occurs between 0 and 15  
208 days, N volatilisation stops; if not then all originally available  $\text{NH}_4^+$  is volatilised. A special case  
209 is the foliar fertiliser applied with sprayers, as typically done for pesticide application. No studies  
210 report rates of  $\text{NH}_3$  volatilisation from foliar urea application to vineyards, only to turf or wheat  
211 crops (Freney, 1997). This research indicates very little N loss from volatilisation, hence  
212 volatilisation losses from foliar fertilisation in vineyards are considered to be negligible.

213

214 Denitrification and  $\text{N}_2\text{O}$  generation are difficult to compute based on mechanistic models, so  
215 IPCC guidelines are used for  $\text{N}_2\text{O}$  emissions evaluation here, i.e. 1% of total remaining N (after  
216 volatilisation) (IPCC, 2006).

217

218 Leaching of nitrates occurs and the fraction of  $\text{NO}_3^-$  leached below a depth  $h$  is calculated by the  
219 Burns formula (Burns, 1975):

$$220 \quad f(t) = \left( \frac{P(t) - ETP(t)}{P(t) - ETP(t) + (V_m / 100)} \right)^h$$

221  
222 where, for a given period of time  $t$ ,  $f(t)$  is the fraction of surface-applied nitrate leached below any  
223 depth  $h$  (cm),  $P(t)$  is the quantity of water brought by rain and irrigation (cm), ETP expresses the  
224 quantity of water lost by evapotranspiration (cm) and  $V_m$  is the percentage volumetric field  
225 capacity.

226  
227 This formula is applied to the excess N (i.e. N which has been mineralised but which is neither  
228 absorbed by plants, nor volatilised, nor denitrified (Kücke and Kleeberg, 1997)) as described by  
229 the nitrogen balance, which stipulates that all N exports (i.e. N emissions and plant-absorbed N)  
230 counterbalance available nitrogen ( $N_m$ ) (i.e. nitrates from fertilisers and mineralised from soil and  
231 crop residues). In order to be more precise, this N balance is calculated on a sub-yearly timeframe  
232 (i.e. monthly) as follows:

$$233$$
$$234 \quad N_m(\text{soil}) + N_m(\text{fertilisers}) + N_m(\text{crop residues}) = N(\text{absorbed by plants}) + N(\text{leaching}) +$$
$$235 \quad N(\text{volatilisation}) + N(\text{denitrification})$$

236  
237 Nitrogen emission can serve as an example to illustrate our way of translating activity, structural  
238 and weather data into emissions. The N balance, the various models described above for  
239 volatilization, denitrification and leaching, as well as the bio- or geo- models for computing of  
240 various properties of the soil - plant system are used to build a general calculator of the N

241 emissions (Figure 1). This conceptual framework is implemented in a spreadsheet (Excel,  
242 Microsoft) which provides amounts of  $\text{N}_2\text{O}$ ,  $\text{NH}_3$  and leached  $\text{NO}_3^-$ , based on readily available  
243 data. The step-by-step procedure is described in Supplementary data S1.

244

#### 245 3.4.2 Phosphorus

246 To compensate for approximately 0.6 kg phosphorus (P) removed per ton of grapes harvested, the  
247 grapevine P requirement is around 10–25 kg/ha/yr (CRCV, 2006). Generally, P is non-limiting in  
248 vineyards, so P supply is often just basic manure application at planting. Once applied, P can  
249 remain in the soil profile for a long time by co-precipitation with  $\text{Ca}^{2+}$  cations in alkaline soils  
250 and  $\text{Al}^{3+}$  or  $\text{Zn}^{2+}$  cations in acidic soils. Phosphorus fertilisers are not prone to volatilisation  
251 (McConnell *et al.*, 2003) and the most important loss factor is run-off and surface soil erosion  
252 (Smith *et al.*, 2001; Peters *et al.*, 2011b). If P is applied in large excess (more than twice the  
253 recommended dose), P in agricultural run-off may contribute to eutrophication (Smith *et al.*,  
254 2001). In this study, Nemecek and Kägi's recommendations were followed to compute P  
255 emissions (Nemecek and Kägi, 2007). However, other models such as the one proposed by Vadas  
256 *et al.* (2009) may be used, which computes P loss as a function of the amount of applied P  
257 (obtained from traceability data), the water-extractable P (which can be included in the database  
258 of fertilisers' structure data), and the run-off and the rainfall amount (collected as a weather data).  
259 Run-off values may not be readily available and Vadas *et al.* (2009) caution readers that the run-  
260 off and erosion estimates are still needed at a level accuracy suitable for their quantification tool.

261

#### 262 3.4.3 Potassium

263 In the vineyard, potassium (K) fertilisation is generally carried out at planting (basic manure) but  
264 regular application may follow. Potassium is present in four cation fractions, three of which are  
265 labile. Potassium losses via leaching greatly depend on the cation exchange capacity (CEC) i.e.  
266 the K-buffering capacity of soil, which is related to organic matter (OM) content and clay type  
267 and content, soil pH, drying/wetting cycles and soil K status. Leaching varies from 0.4–5 kg  
268 leached K per 100 mm drainage, according to soil texture and OM content with an average of 1  
269 kg leached K per 100 mm drainage (Askegaard *et al.*, 2004); up to 70% of applied K could  
270 remain in heavy soils after the first growing season, whereas in coarse sandy soils a high risk of  
271 K leaching occurred at around 20–50 kg K/ha/yr (Askegaard *et al.*, 2004). Catch crops may  
272 reduce nutrient leaching (Askegaard and Eriksen, 2008). In summary, K leaching can be  
273 modelled similarly to N leaching (i.e. Burns' formula).

274

### 275 3.5 Pesticides

276 Vineyards are very pesticide-intensive. For example, in France, vineyards represent 4% of the  
277 total cropped area but use some 20% of all consumed pesticides (Gil *et al.*, 2007). Pesticide  
278 losses can occur either from “point source pollution” (accidental pollution estimated 10% of total  
279 losses by experts) and “diffuse pollution” (from normal use). Diffuse pollution is linked to mist  
280 and droplet drift during spraying, vapourisation of pesticides during and after spraying, particle-  
281 born pesticide run-off, aerial transport and leaching. The inventory challenge resides in the  
282 partitioning of pesticides into air, plant and soil compartments (Van Zelm *et al.*). Sinfort *et al.*  
283 (2009) studied drift and concluded that: (1) all other conditions being equal, drift loss mainly  
284 depends on the type of sprayer used (boom sprayers, air-assisted or pneumatic sprayers, etc.); and  
285 (2) partitioning mainly depends on the vegetative stage. Other secondary parameters influencing

286 drift are wind speed, droplet size distribution and the wet bulb depression (related to temperature  
287 and humidity) (Gil *et al.*, 2007; Gil *et al.*, 2008). Drift mitigation technologies have been shown  
288 to change pesticide partitioning (Sinfort *et al.*, 2009); cross-flow spraying significantly reduced  
289 losses to air (up to 50%), but yielded inconsistent results for losses to soil, whereas air deflectors  
290 did not provide any improvement. Accordingly, the principal factors considered by our approach  
291 are: (1) the technology used; and (2) the date of spraying. Based on the data in Sinfort *et al.*  
292 (2009) for a pneumatic sprayer, in our study the following air–plant–soil partition is chosen:  
293 0.4:0.2:0.4 and 0.1:0.5:0.4 respectively for “early” (before flowering) and “late” (after flowering)  
294 spraying.

295  
296 Pesticide volatilisation mainly occurs from spray deposits (Van Den Berg *et al.*, 1999). The main  
297 factors involved in post-application volatilisation are rainfall, wind speed, temperature, solar  
298 radiation, relative humidity, active ingredient and adjuvant physicochemical features such as  
299 vapour pressure and  $K_{ow}$  (a measure of hydrophobicity) (EPA, 1995; Bedos *et al.*, 2010).  
300 Volatilisation from leaves ( $Pest_v$ ) is computed via PestLCI formulas (Birkved and Hauschild,  
301 2006):

$$302 \quad Pest_v = f_{vf} \cdot Pest_0 \text{ with } f_{vf} = e^{-k_v \cdot t} \text{ with } k_v = f(K'_H)$$

303 Where  $f_{vf}$  is the fraction on leaves which volatilises;  $t$  is time;  $k_v$  is the volatilisation coefficient;  
304  $K'_H$  is Henry's constant for volatility.

305  
306 Pesticide leaching from leaves is estimated by a common rule of thumb. It is commonly  
307 considered that if a 20 mm rain event occurs within three days after spraying, 100% of pesticide  
308 is leached. Pesticide leaching in soil is modelled as  $K^+$  and  $NO_3^-$  leaching following Burns'

309 equation. No pesticide run-off or pesticide degradation is taken into account at this stage, as they  
310 are considered to be part of the LCIA model (Van Zelm *et al.*, 2014).

311

312

## 313 **4. Results**

### 314 4.1 LCI and LCIA data

315 LCI and LCIA data obtained using our approach for the five case studies are described and  
316 presented in Supplementary data S2–3 respectively.

317

### 318 4.2 Relevant impact categories in LCA of viticultural operations

319 In order to determine which of ReCiPe's 18 impact categories are most relevant in this case, the  
320 results were normalised against global emissions using the ReCiPe normalisation procedure  
321 (<http://www.lcia-recipe.net/>). Normalised outputs of grape production on P80, years 2004, 2006,  
322 2008 are shown in Figure 2. As frequently encountered in viticulture, the most relevant impact  
323 categories are those relating to toxicity, followed by eutrophication, and to a lesser extent, global  
324 warming potential and terrestrial acidification. Impacts are primarily linked to pesticide spraying.  
325 The following analysis is, therefore, constrained to these most relevant impact categories.

326

### 327 4.3 Contribution analysis of the various operations

328 As previously mentioned, viticultural operations have been divided into the following operation  
329 classes: tillage (for any soil management operation); operation on canopy (trimming, pruning,  
330 etc.); pesticide spraying; fertilising; and grape harvesting. As the operations do not vary much  
331 from year to year and plot to plot, we have chosen to illustrate the impact contributions for one of



332 the five case study configurations only, i.e. P80 2006 which is common to both of the tested  
333 variables (i.e. yearly and soil variability). Results are shown in Figure 3.

334  
335 Tillage often makes a bigger contribution to environmental impacts than harvesting, but the  
336 impacts of these two activities tend to vary in proportion compared with the much more variable  
337 impact of fertilisation (data not shown). This could be expected, as both tillage and harvesting  
338 operations are primarily physical operations involving machinery and diesel. The most heavily  
339 impacted category is fossil fuel depletion, due to diesel use. Fertilising mainly impacts climate  
340 change (via  $\text{N}_2\text{O}$  emissions) and marine eutrophication (via  $\text{NO}_3^-$  emissions), whereas pesticide  
341 spraying exerts a major influence on toxicity indicators.

342  
343 4.4. Synthesis: necessary data for LCI compilation.

344 Based on the farm traceability data—supplemented with weather and structural data—and using  
345 the principles and formulas described above, data inventories and impact assessments have been  
346 calculated. For illustrative purposes, let us consider the example of emissions due to N  
347 fertilisation. The emissions come from three sources: the production of fertilisers; the use of  
348 machinery; and the field. For emission due to fertiliser production, traceability data such as  
349 fertiliser dose and fertiliser type are requested and Ecoinvent LCI data are used. For emissions  
350 due to machinery use, the emission due to machinery manufacture are computed from Ecoinvent  
351 database whereas emissions due to machinery work require traceability data such as the duration  
352 of operation and if possible the speed. Table 4 can then be used to compute emissions from diesel  
353 consumption. Field emissions are by far the most complex and require the following data:  
354 traceability data such as fertiliser dose and type and application date; weather information; and  
355 structural data such as fertiliser properties and soil properties. The way such data are employed in

356 our spreadsheet to compute N emissions has been shown in Supplementary data S1. Due to space  
357 constraints, the same demonstration cannot be repeated for all emission types; however, data  
358 necessary for carrying out LCI development in viticulture are summarised in Table 6.

359  
360 Individual pieces of data may be discrete (e.g., time, mass, etc.), binary (Yes/No; Low/High) or  
361 descriptive/nominal such as name  $N_x$  to be taken from a list  $x$  (e.g., operations, equipment,  
362 fertiliser and pesticide names). Names in lists are linked to another database containing the  
363 specific properties which are required for computing emission factors. For instance, each  
364 pesticide name is related to its formulation and the active ingredient, physico-chemical properties  
365 ( $K'_H$ ) which can be found in public databases such as Material Safety Data Sheets displayed in  
366 <http://e-phy.agriculture.gouv.fr/> and (EPA, 1995). The same process must be carried out for  
367 equipment. For each type of machine/infrastructure, data regarding emission/consumption for one  
368 hour use are recorded (e.g., embedded emissions, fuel consumption and sensitivity to speed,  
369 presence of emission mitigation components such as those for pesticide spraying or fertiliser  
370 spreading, and number of rows covered by one vineyard passage). Major pieces of data are listed  
371 as “1”, whereas secondary data are listed as “2”. Data are classified according to their origin, i.e.  
372 “operational data”, “weather data”, and “plot data”. “Plot data” and “name lists” are structural  
373 data.

374 Data required for these models were shown to be easily available: most are collected from  
375 traceability registers and supplemented with additional data. “Operational data” must be recorded  
376 for each operation. Out of six pieces of operational data which are of primary importance for  
377 emission computation (i.e. noted “1” in Table 5, column 5 to 8), only one (work duration) is not  
378 required for traceability. However, it is easily accessible, provided that the operator maintains a log  
379 book. Driving data are also likely to be increasingly recorded on an automatic basis in future via

380 odometers and on-board computers, or perhaps smart phones. Weather data can be automatically  
381 downloaded from local weather stations. “Structural data” relate to data describing the farm  
382 infrastructure, including machinery. Such data are generally not requested for traceability. Even if  
383 recording them requires additional work with regard to traceability, it is not laborious as they are  
384 recorded once only and can then be called upon as required.

385

## 386 **5. Discussion**

387 The discussion deals with two points. First, which confidence level can we put into our  
388 procedure? To address it, our results have been compared to others found in the literature.  
389 Second, which uncertainty level is to be expected? To have a trend, sensitivity analyses have  
390 been carried out.

391

### 392 **5.1. Comparison with other viticultural LCAs**

393 In order to check the soundness of our approach, some of our results have been compared with  
394 relevant literature data. Although publications regarding viticultural LCAs are scarce and  
395 generally do not give figures appropriate for robust comparison, one publication (Vázquez-Rowe  
396 *et al.*, 2012) was very relevant to our study as it deals with 30 vineyards in Spain, with a climate  
397 close to the Mediterranean zone in which our study is based. Values of three midpoint impact  
398 categories common to both studies (i.e. global warming potential (GWP), acidification potential  
399 (AP) and eutrophication potential (EP)) were compared. As (Vázquez-Rowe *et al.*, 2012) used  
400 the CML method, not ReCiPe, computations for the present comparison were redone using this  
401 LCIA method.

402 Table 6 shows a very good level of similarity (generally of the same order of magnitude or better)  
403 between the results of our five case studies and those of the 30 case studies introduced by

404 (Vázquez-Rowe *et al.*, 2012), which suggests the precision of the proposed approach is  
405 satisfactory. Our methodology has the additional advantage of making it possible to study effects  
406 of weather or soil, which was not the case of the methodology presented by (Vázquez-Rowe *et al.*,  
407 2012).

408

#### 409 5.2. Sensitivity of LCI and LCIA computations to soil conditions

410 Impacts estimated on plots with similar practices but having three different soils are compared in  
411 Figure 4. One plot, P22 2006, has systematically lower impact values than the two others. This is  
412 due to the fact that the yield is much higher in this plot (almost the double of the other ones, as  
413 shown in Table 3). The only category which displays similar values across all three plots is  
414 marine eutrophication, which is due to  $\text{NO}_3^-$  leaching, suggesting that the mass of nitrate  
415 leaching from P22 2006 plot is large. This comes not only from the fact that more fertiliser is  
416 applied, but also as a consequence of soil texture: P22 plot is a very sandy soil (see Table 2)  
417 which is consistent with a higher rate of leaching. P80 2006 and P103 2006 have similar yields,  
418 P80 2006 being slightly higher (5000 versus 4400 kg/ha). This explains why in most cases, P80  
419 2006 impacts are generally smaller or equal to P103 2006 impact values (Figure 4). The sole  
420 category for which P80 2006 exceeds P103 2006 is fossil fuel depletion. This is linked to  
421 increased consumption of fuel for P80 2006, due to the fact that its soil is difficult to handle and,  
422 therefore, machinery fuel consumptions were increased by 30%.

423

#### 424 5.2 Sensitivity of LCI and LCIA computations to yearly variations

425 Figure 5 shows the impacts computed for the same plot (P 80) on three different years (i.e. 2004,  
426 2006 and 2008). The large between-year discrepancy is due to a drop in yield for study year  
427 2008, i.e. yield has declined by 75% (see Table 3). Focusing on 2004 and 2006, it can be noticed

428 that 2006 always gives higher impacts than 2004. This is due to the better yield in 2004, whereas  
429 agricultural practices are similar (e.g., same amount of fertiliser applied) or improved in 2004.  
430 For example, there are seven runs of pesticide spraying in 2006 versus five in 2004, and relatedly,  
431 17 types of pesticides applied in 2006 versus 14 in 2004, presumably due to differences of  
432 weather and of phytosanitary pressure from one year to another. This compounding factor is  
433 visible when ratios of 2006:2004 impacts are computed; these ratios are larger across all five  
434 impact categories related to pesticide inputs (ratios for toxicity, ecotoxicity and freshwater  
435 eutrophication range from 1.3–2.6, with an average of 1.7) than for the other categories (i.e. ratios  
436 for climate change, fossil depletion and marine eutrophication vary from just 1.16–1.2, with an  
437 average of 1.2). As in the preceding case, the main driver for impact changes is the variations in  
438 yield.

439

440

441

## 442 **6. Conclusion**

443 Two principal conclusions are supported by this study. Firstly, precise LCI can be developed using  
444 traceability data, a small number of additional data and simple models and heuristics, as shown by  
445 the very good correspondence of our results to previously published LCA data related to winegrape  
446 production. Secondly, an LCA procedure such as this allows us to analyze sources of variability,  
447 such as soils or weather, in LCIA of agricultural productions, here vineyards.

448 Regarding LCI, it has been demonstrated that extensive data inventories could be obtained with  
449 little effort by using simple models and a limited amount of data, most of them being collected for  
450 traceability purposes. The analysis of data necessary for LCI, reported in Table 5), showed that  
451 only three pieces of data would be required in addition to traceability data recorded in the crop

452 book: the work duration, the type of equipment used and the origin of water (if irrigation is used).  
453 Work duration could be automatically collected using ISOBUS system (see part I) and the type of  
454 equipment is already easily collected in current agricultural equipments by using a flashcode.. This  
455 means that only three out of eight pieces of operational data should be collected in addition,  
456 whereas soil data would be collected once and for all and weather data could be automatically  
457 collected.

458  
459 When applying this methodology to vineyards, it has been shown that precise inventories could be  
460 generated on various real case studies, i.e. grape growing in the south of France. The contribution  
461 study contributed to identify pesticide spraying as the most impactful operation on toxicity  
462 indicators, while fertilisation influenced GWP and eutrophication potential impact categories,  
463 although generally not as greatly as encountered elsewhere in agriculture. The sensitivity analysis  
464 showed the overwhelming influence of yield on the final results, which is logical given the use of a  
465 fixed product mass as the functional unit. However, when yields are comparable, other secondary  
466 factors also influence the results. For instance, in the temporal comparison, the highest use of  
467 pesticides was visible (P80 2004 versus P80 2006 comparison), whereas in the soil sensitivity  
468 study, the sandy soils gave higher potential marine eutrophication impact.

469  
470 In conclusion, our goal of generating viable LCI databases for streamlined LCAs in viticulture is  
471 within reach. Models presented here will be of value to anybody intending to carry out a LCA on  
472 grape or even other fruit production. Most data is available today or should be easily available in  
473 the future. Traceability software editors could now modify the traceability database structure  
474 according to the recommendations of this study in order to further streamline agricultural LCI data  
475 generation.

476

#### 477 **Acknowledgements**

478 This paper was written partly from the work carried out with traveling scholarship supported by  
479 the European Commission (IRSES program, project nr 235108), the Languedoc Roussillon  
480 Council (Regional Plat-form GEPETOS – ECOTECH-LR) and PEER (Partnership for European  
481 Environmental Research) and partly from the work carried out in an Interreg IV B project,  
482 supported by FEDER (Ecotech-Sudoe, SOE2/P1/E377). The authors also thank Dr B Langevin, C  
483 Gaviglio, B Tisseyre and M Schulz for their assistance.

484

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Table 1: Example of a traceability log table from the Agreo software (here plot P80, year 2006) (Source: INRA).

<b>Name :</b>	# 80	<b>Species :</b>	Vineyard		
<b>Zone :</b>	XXX	<b>Variety :</b>	Syrah		
<b>Area :</b>	0.69 Ha				
<b>Harvest :</b>	2193 kg				

<b>Fertilising</b>	<b>Commercial name</b>	<b>Quantity</b>	<b>N</b>	<b>P</b>	<b>K</b>
28/09/2006 – Fertilisation	Orga 3 (3-2-3)	907 kg	27	18	27

<b>Harvest</b>	<b>Input Name</b>	<b>Quantity</b>
30/08/2006 –Harvest		2193 kg

<b>Pesticide spraying</b>	<b>Commercial name</b>	<b>Quantity</b>	<b>Target</b>
11/05/2006 – Miscellaneous	Acarifas	0.5 L/Ha	Clysia
	Sabithane	0.3 L/Ha	Powdery Mildew
	Epylog	3 kg/Ha	Mildew
	Goemar vitiflo E	3 L/Ha	
22/05/2006 – Miscellaneous	vitiflo E	3 /Ha	
	Corail	0.4 L/Ha	
	pantheos (4522C8)	2 kg/Ha	
06/06/2006 – Miscellaneous	Quadris	2 L/Ha	
	Vivifruit	1 L/Ha	

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15/06/2006 – Fungicide	Sulphur (4/336)	30 kg/Ha	
23/06/2006 – Miscellaneous	Cascade	0.4 L/Ha	Clysia
	Karaté K	0.125 L/Ha	Leafhopper
	Microthiol	10 L/Ha	Powdery mild.
08/07/2006 - Fungicide	Vifolcuivre2	3 /Ha	Mildew
	Heliosoufre	7.5 L/Ha	
27/07/2006 – Miscellaneous	Champ Flo	4.3 L/Ha	Mildew
	Steward	0.125 U/Ha	Clysia
<b>Tillage</b>			
03/03/2006 – Harrowing			
24/04/2006 - On-the-row weeding			
16/05/2006 – Harrowing			
17/05/2006 - Interstock tillage			
02/10/2006 – Harrowing			
<b>Canopy management</b>			<b>Output Quantity</b>
13/06/2006 – Trimming			
03/08/2006 – Trimming			
01/12/2006 – Pruning			Unknown
05/12/2006 – Pruning residues shredding			

Table 2: Characteristics of the three grapevine plots under study.

Plots	P 103	P 80	P 22
Soil type	A	B	C
Interrow distance (m)	2.25	2.25	2.5
Ground workability	Easy	Difficult	Easy
Texture	Clayey	Clay and stones	Sandy
Clay (ppt)	500	800	100
Bulk density (kg/m <sup>3</sup> )	1200	1100	1700
Organic matter content (%)	2	1	1
Soil depth (h in mm)	500	300	300
CaCO <sub>3</sub> (ppt)	100	200	10
% stones	10	50	0



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Table 3: Grape growing operations for the five plots under study. The type of equipment and names of inputs are known for each operation but not reported here.

Case ID	P103-06	P22-06	P80-06	P80-04	P80-08
Soil type	A	C	B	B	B
Year	2006	2006	2006	2004	2008
Yield	4435 kg/ha	8910 kg/ha	5060 kg/ha	5640 kg/ha	1027 kg/ha
Pesticide Spraying <sup>a,b</sup>	7 runs, various dose (15 sprays)	8 runs*, various dose (18 sprays)	7 runs, various dose (17 sprays)	5 runs, various dose (14 sprays)	8 runs*, various dose (14 sprays)
Fertiliser Spreading <sup>a</sup>	700 kg/ha	1000 kg/ha	907 kg/ha	907 kg/ha.	907 kg/ha
Tillage	5 runs	4 runs	4 runs	3 runs	2 runs
Canopy operations	Binding , pruning	Pre-pruning, trellising, trimming pruning	Shoot crushing, pruning	Trellising and pruning	Bud removal trimming, pruning

<sup>a</sup> The name of inputs are known for each operation but not reported here;

<sup>b</sup> one pesticide run can use between 1–4 pesticides, giving the total number of sprayings

\* Means “including weeding”

Table 4: Diesel consumption (L/h) for various viticultural operations, including sensitivity to forward speed and to a lower engine speed

Vehicle tool	Speed (km/h)	Fuel consumption (L/h)	Sensitivity to lower engine speed (economic drive)	Sensitivity to speed (for + 1km/h)	Ref
Disc harrow	5	12.3	-17%	+18%	a
Surface harrow*	5	9.5			a
Inter-vine rotatory	2.5	15	-27%		a
Mowing	5	14	-35%	+4%	a
Shoot shredder	4	8.3	-25%	-12%	a
Sprayer	6	14.4	-30%		a
Grape harvester	3.5	43		+50%	b
Vine topping	6	15.2		+25%	b
Pre-pruning	5	22.7			b
Vine lifting	4	15			b
Farm – plot drive	30	18–27			c

\* surface harrowing (for deep harrowing, increase fuel consumption by +50%)

<sup>a</sup> (Gaviglio *et al.*, 2009); <sup>b</sup> IFVV (French institute of wine and vine) and equipment manufacturers; <sup>c</sup> IRSTEA

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Table 5: Data required to compile LCI in viticulture; 3<sup>rd</sup> column relates to “traced data” (X where data is already traced); 4<sup>th</sup> column relates to pieces of information that must be linked to each name in the name lists which is; columns 5<sup>th</sup> to 8<sup>th</sup> refer to the prominence of this piece of data for computing emissions of this operation (1 = very important, 2 = secondary); all data marked \* are structural data.

Key	Primary data	Traceability	Linked information	Equipment	Irrigation	Fertilisation	Pesticide
<b>OPERATION DATA</b>							
No	Name of operation*	X	Equipment (Nm) Input (Nf, Np, Ni)	1	1	1	1
Nm	Name of equipment*		Hourly consumption Sensitivity to Sp, Se and Sl Mitigation technologies	1			
T	Work duration			1	1		
Sp	Speed			2			
Se	Engine speed (low / high)			2			
Np	Name of pesticide*	X	Active ingredient K'h & Kv				1 1
Nf	Name of fertiliser*	X	N-P-K content % organic N Coefficient of volatilisation Coefficient of mineralisation			1 1 1 1	
Ni	Name of water source		Groundwater or surface water				
Q	Applied quantity	X			1	1	1

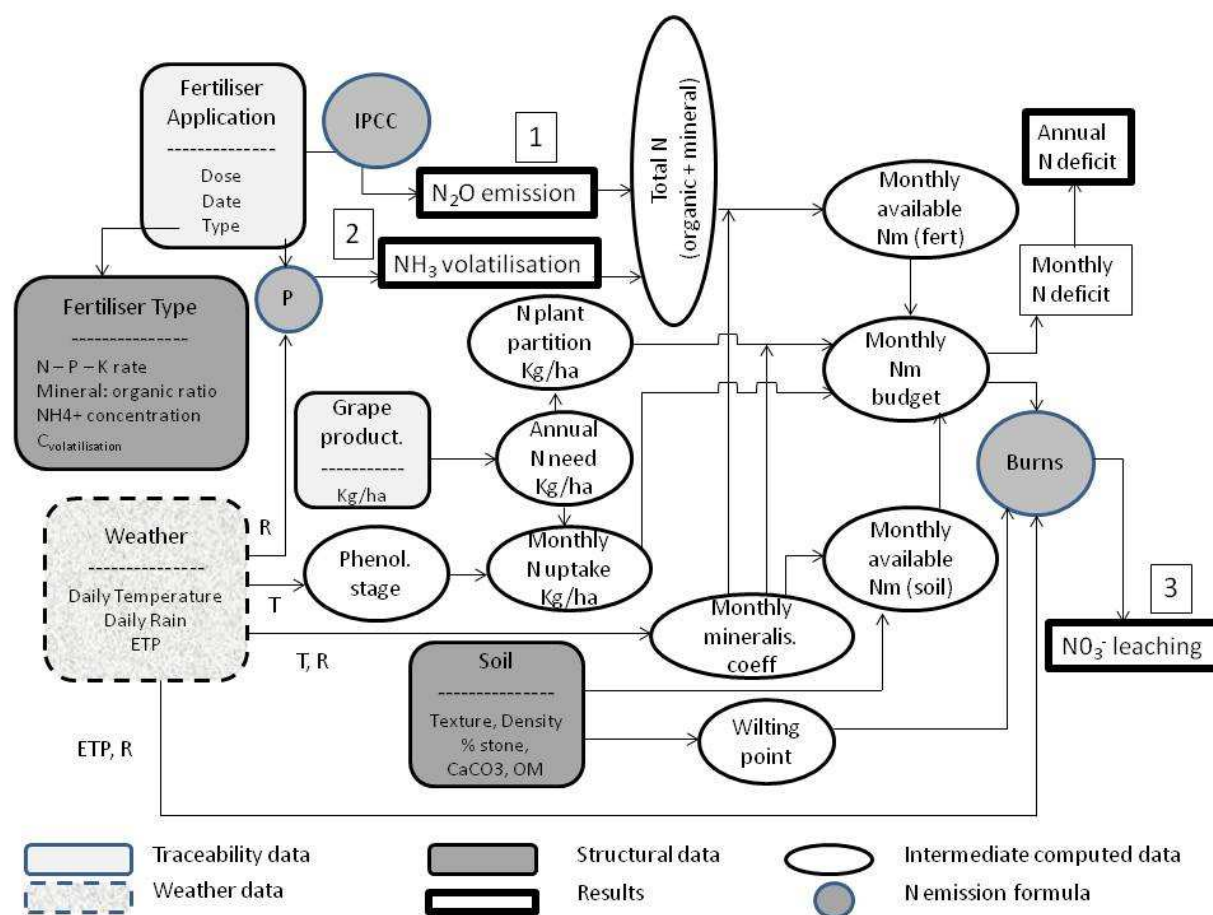
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D	Application date	X				1	1
WEATHER DATA							
P	Daily precipitation					1	2
T	Temperature					1	
PLOT DATA							
IR	Interrow distance*				1		
De	Nb of stocks per ha*	X			1		
Sd	Soil data*		Texture			1	
			Organic matter content			1	
			CaCO <sub>3</sub> content			1	
Di	Plot-farm distance*				1		
Sl	<i>Soil hard to handle*: slope, stones... (Yes/No)</i>				2		
Wd	Water Table depth*					1	

Table 6: Comparison of the values obtained for three midpoint impact categories for our case study (5 samples) and Vázquez-Rowe *et al.* (2012) data (30 samples).

	Acidification Potential (g SO <sub>2</sub> eq)		Global Warming Potential (g CO <sub>2</sub> eq)		Eutrophication Potential (g PO <sub>4</sub> <sup>2-</sup> eq)	
	Vazquez-Rowe <i>et al</i>	Our case study	Vazquez-Rowe <i>et al</i>	Our case study	Vazquez-Rowe <i>et al</i>	Our case study
Mean	4.2	2.4	462	461	1.5	0.9
Lowest	1.2	0.7	160	156	0.3	0.4
Highest	8.6	7.4	910	1392	8.0	2.3

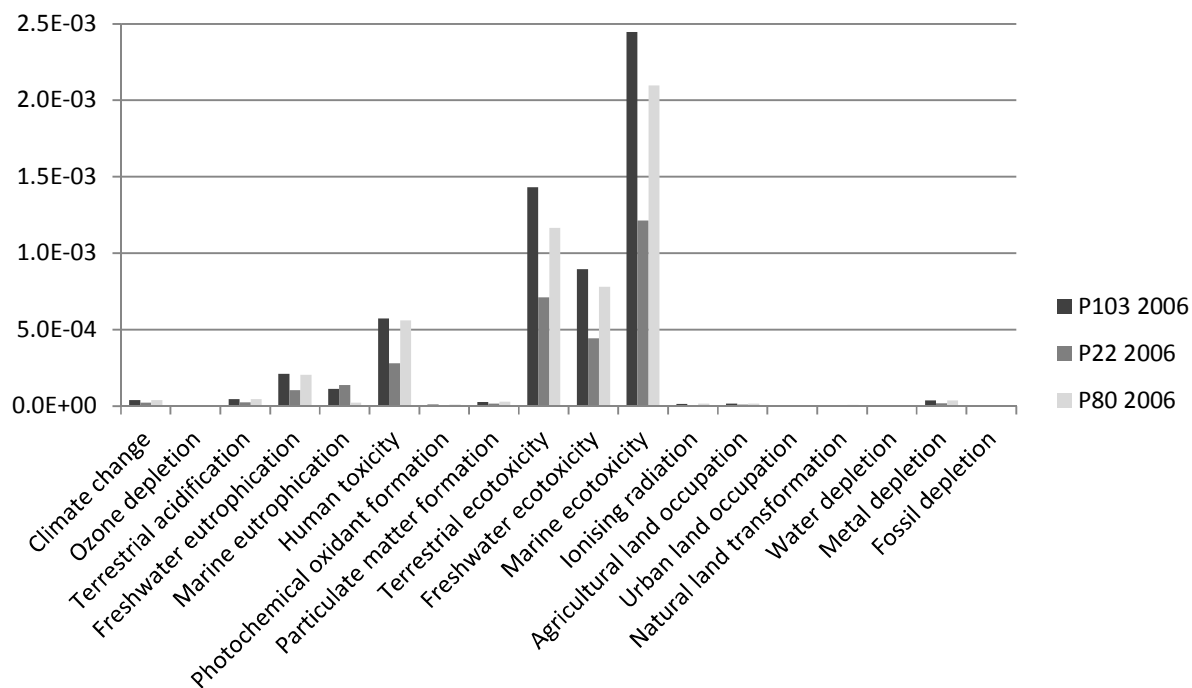
1



2

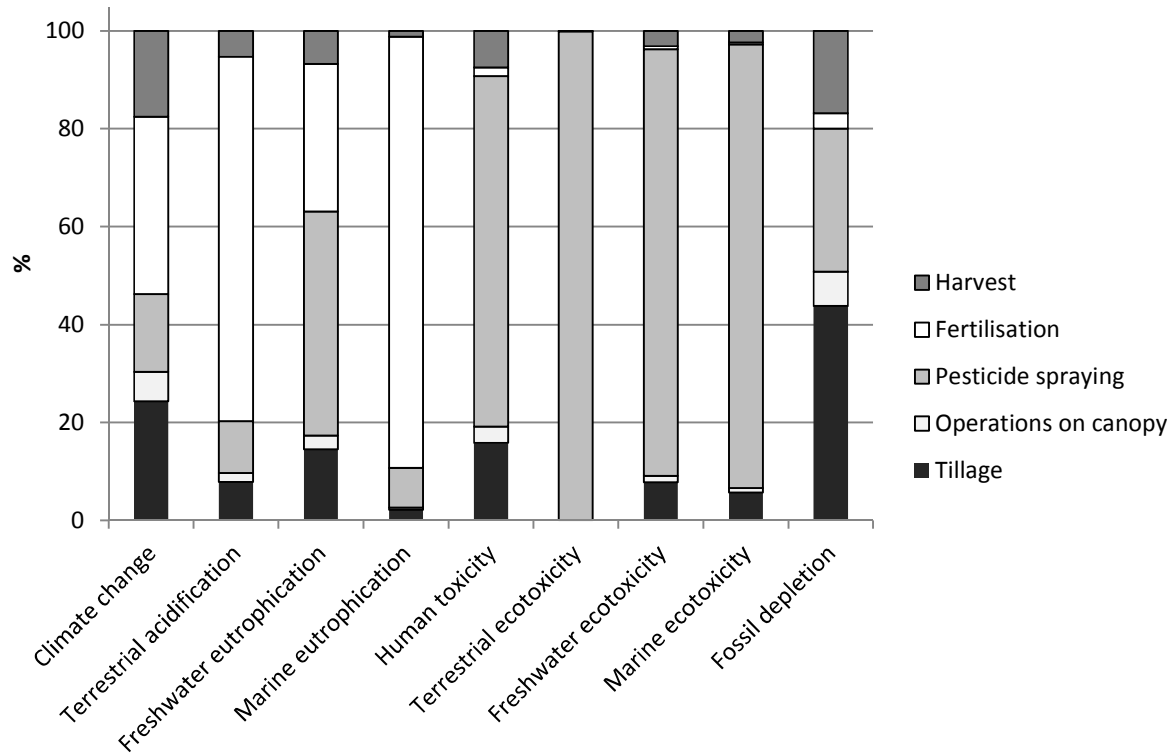
3 Figure 1: Conceptual framework showing how field N emissions are computed based on  
 4 traceability, weather and structural data. Figure numbers 1–3 show the order of computation in  
 5 the algorithm. P stands for PestLCI formula, R for Rainfall, T for temperature, ETP for  
 6 evapotranspiration, OM for organic matter.

7



8  
9 Figure 2: Normalisation of LCA outputs for 1 kg Syrah grape production grown in three different  
10 plots on the same year (ReCiPe Midpoint (H) V1.07 / World ReCiPe H)

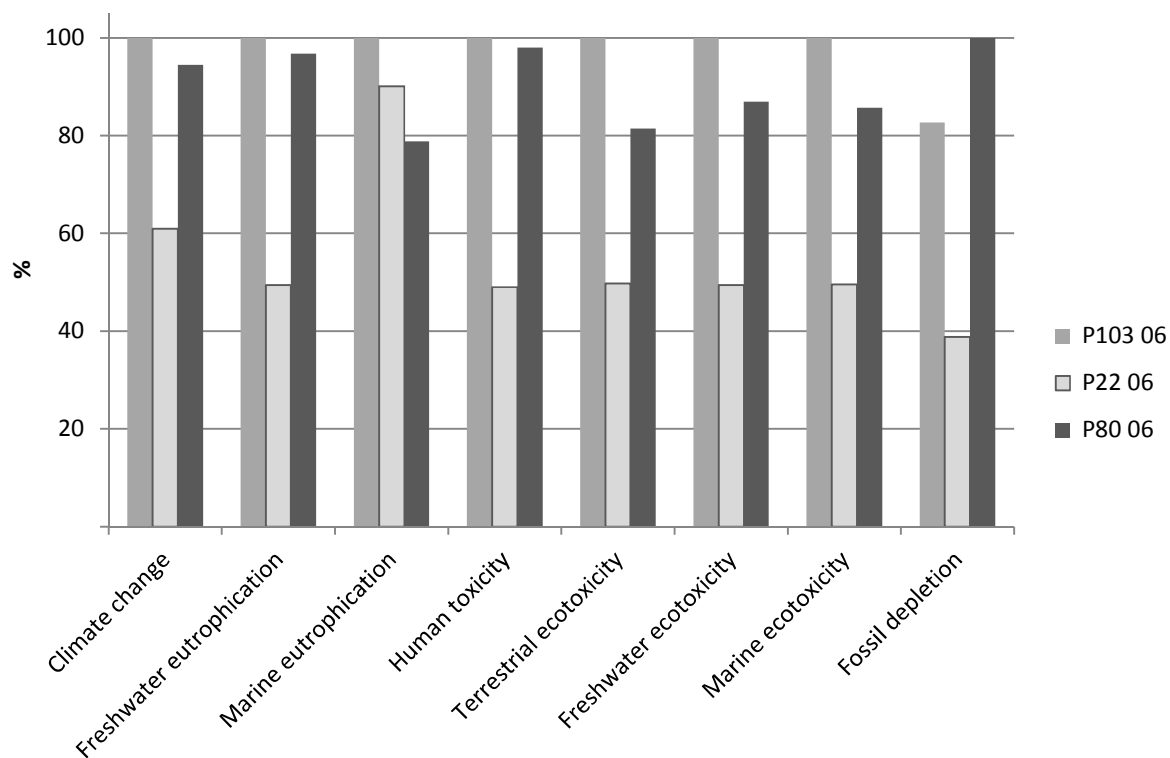
11



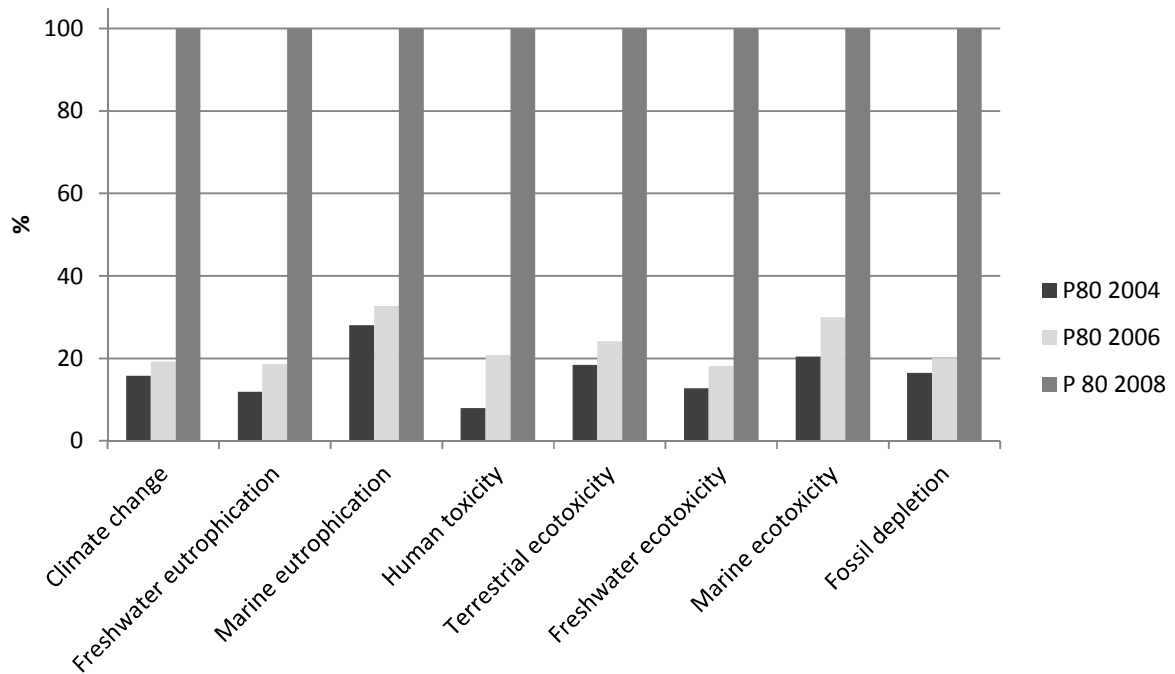
12  
13 Figure 3: Contributions of the various viticultural operations to LCIA of grape production (Plot P  
14 80 2006; FU = 1 kg grape production; ReCiPe Midpoint (H) V1.07 / World ReCiPe H)

15





16  
17 Figure 4: LCIA of the production of 1 kg grape of the same variety (Syrah), on the same year  
18 (2006), in three different plots having different soils of the same farm in South of France; P103  
19 2006, P22 2006 and P80 2006 (characterisation by ReCiPe Midpoint (H) V1.07 / World ReCiPe  
20 H).  
21



22  
23 Figure 5: LCIA of the production of 1 kg grape of the same variety (Syrah), on the same plot (P  
24 80) and on three different years (2004, 2006, 2008) in South of France (characterisation by  
25 ReCiPe Midpoint (H) V1.07 / World ReCiPe H).

26  
27

## Supplementary data S1: Step-by-step procedure for computing nitrogen losses

### Step 1: Volatilisation

The potential volatilisable N is computed as

$$N_{vol} = N_{NH4+} \times C_v$$

where  $N_{NH4+}$  is the amount of  $NH_4^+$  in the fertiliser input,  $C_v$  is the volatilisation coefficient.

But if rain falls, it is assumed that  $NH_4^+$  infiltrates and therefore is no longer available for volatilization. Therefore, we consider  $N_{NH4+}$  has a half-life of 12 hours, and this process may be stopped by rain. Therefore

$$N_{NH4+} = N_{NH4+_tot} \cdot (1 - e^{-\lambda \cdot t})$$

With  $\lambda$  is the half-life ( $\lambda = 0,5$  days) and  $t$  is the number of days with no rain ( $> 20$  mm) after spreading.

$$N_{remain1} = N_{tot} - N_{vol}$$

### Step 2: Denitrification

The assumptions contained in the IPCC protocol (2006) are used, once volatilized N has been removed:

$$N_{denit} = 1\% \cdot N_{remains1}$$

$$N_{remains2} = N_{remains1} - N_{denit} = 99\% N_{remains1}$$

### Step 3: N leaching

Leaching is treated in two separate ways depending on whether the N sources are organic or mineral. Organic N must first be turned into mineral N. This deals with N from organic fertiliser, from soil and from vegetal organs (for instance leaves or shoots of year  $n-1$ ).

#### Sub-step 1: Monthly mineralized nitrogen

We make the assumption that mineralization of organic fertilisers and vegetal organs follow soil mineralization monthly kinetics (but with different levels).

First step is to compute the maximum potential mineralized N for each source of organic N.

For fertilisers, it depends on the fertiliser type and this amount is part "f" the fertiliser database;

For vegetal organs, the potentially mineralized N is the amount of plant material which is not humified; the humification coefficient  $k_1$  depends on the type of organ ( $k_1$  varies from 0,1 for mown grass to 0,25 for pruning residues). In order to know the total amount of potential mineralizable N in a year, i.e. the total

amount of leaves, shoots, the grape production of year (n-1) must be known as well as the way the plot is cultivated (covered crops with mown grass, shoots removed or left on the soil...);

For soil, the maximum mineralized N is provided by the annual mineralization rate  $K_{2pot}$ , which is given by the following formula (Machet et al, 1990)

$$K_{2pot} = 1200 \times [(0,2 \cdot T_{moy}) - 1] / [(clay + 200) \times (0,3 \cdot CaCO_3 + 200)]$$

Where  $T_{moy}$  is the annual mean temperature once the base Temperature ( $T_{base}$ ) has been subtracted ( $T_{base} = 10^\circ\text{C}$  for soil microorganisms); clay is the amount of clay in per thousand,  $CaCO_3$  is the amount of calcium carbonate in parts per thousand.

Monthly, the mineralization also depends on the soil moisture,  $f(t,H)$ : experts describe  $f(t,H)$  as a bell-type curve with a maximum at moisture just below field capacity. It is zero for moisture below wilting point or beyond field saturation.

Therefore for organic sources of N

$$N_{min}(t) = K_{2pot} * N_{remains2(organic)} * f(t,H)$$

This rule is used to compute a monthly mineralization rate of soil N.

The same  $f(t,H)$  function is applied to fertilisers potential mineralized N and for vegetal organs.

At the end of this step, the monthly available mineralized N is known

#### Sub-step2: Monthly plant N needs.

The total N need is given by the grape production rate. Needed N is computed from the grape production. For 9-10 T of grapes (/ha), from 45 to 80 kg N are uptaken by the whole plant (Biala, 2000; Guilbaut, 2006).

Monthly uptake is computed based on expert knowledge giving the general profile of uptake by vines during the year (Gary, 2007), according to the phenological stages.

In our calculator, the phenologic stages are computed from the degree days, calculated from weather data.

At the end of this step the monthly N uptakes by the plant are known.

#### Sub-Step 3: Monthly mineralized nitrogen balance

The monthly balance of mineralized N is computed, by removing N uptake (sub-step 2) from mineral, ie available, N (sub-step 1).

If there is a N excess, it is likely to be leached (provided that the conditions are favorable to leaching);

If there is a N deficit, it is accounted for.

#### Sub-Step 4 : Leaching computation

Leaching for each day ( $t$ ) is computed from in excess N, by using the Burns formula (Burns, 1975):

$$f(t) = \left( \frac{P(t) - ETP(t)}{P(t) - ETP(t) + (V_m / 100)} \right)^h$$

where, for a given period of time  $t$ ,  $f(t)$  is the fraction of surface-applied nitrate leached below any depth  $h$  (cm),  $P(t)$  is the quantity of water brought by rain and irrigation (cm), ETP is the amount of water lost by ETP (cm) and  $V_m$  is the percentage volumetric field capacity.

$V_m$  is computed from the knowledge of soil texture.

P and ETP are known from weather data

Total leaching is the sum of the amount of N leached each day.

### Conclusion

Finally, necessary data for N emission computation are:

= The amount of fertiliser spread;

= The date(s) of spreading;

= The type of fertiliser and associated data (see Figure 1, in the manuscript text);

= Weather data;

= Soil data;

= Grape production (year  $n$  and  $n-1$ ).

This process has been implemented on an EXCEL spreadsheet, which makes it easy to use. A graphical depiction of the input/output spreadsheet is given in Figure S1. For other emissions types, the same type of procedure for making simple but relevant and timely models has been carried out.

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Full Amount of Fertiliser (Ton/ ha)	Month of Appli.	Incorporation in the soil? (first 24h)	N_ORGA (n-1)	N_ORGA (n-2)	Rain during the first 7 days ? Which day?
0,7	September	Non	3,26	2,80	0
Name of the fertilizer	Type of soil / Limestone	O.M. in the Soil (%)	CaCO <sub>3</sub> (in parts per thousand )	Soil Horiz with O.M. (in cm)	Average annual temperature (°C)
Orga 3	No limestone	2%	100	20	15
Mineral Fertiliser with controlled liberation?	Soil depth (in mm)	Soil bulk density (in Kg/m <sup>3</sup> )	Amount of Clay (in parts per thousand)	C/N of O.M. in the soil	% of stones
Yes	500	1200	500	10	10
	Type of Soil?	Soil wilting point	Year of Appli.	Bud burst date	Production (Ton/ha)
	CLAYEY-SILTY	30	2006	05/03/2006	9
RESULT	VOLATILISED N Kg N-NH <sub>3</sub>	DENITRIFIED N Kg N-N <sub>2</sub> O	LEACHED N Kg N-NO <sub>3</sub> <sup>-</sup>	N ABSORBED BY PLANTS (Kg-N)	N DEFICIT (Kg-N)
	1,71	1,13	14,68	49,20	1,20

	Traceability data		Data chosen from a list (database)
	Structural data		Computed data

Figure S.1: Spreadsheet built up for computing N emission from traceability (in light grey), structural (medium grey) and weather data (dark grey). Hashed boxes show data which are chosen in a list (ex: list of soil texture, list of fertilisers), and which are related to a database of the properties. Dotted boxes are obtained from computation. Note that daily weather data used for computation are linked from another file.

## References

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- Machet J.M., Dubrulle P., Louis P. (1990) AZOBIL, a computer program for fertilizer N recommendation based on a predictive balance sheet method, in Proceedings of the 1<sup>st</sup> Congress of the European Society of Agronomy, Paris, 5 - 7 december 1990, pp 2-21

## Supplementary data S2: LCI data

### P80 2004

#### Equipment

Soil management		
	Fuel consumption L/ha	Hours/ha
In-row superficial tillage	38.00	4.00
Intercep tillage/ mechanical weeding tillage	0	
stone crushing	0	

Fertilisation		
	Fuel consumption L/ha	Hours/ha
fertilisation	3.20	0.36

Pesticide Spraying		
	Fuel consumption L/ha	Hours/ha
Pesticide/Foliar fertiliser spraying	32.09	2.22
Chemical weeding	0	

Canopy management		
	Fuel consumption L/ha	Hours/ha
pre-pruning	0	
trimming		
vine lifting	35.55	1.78
disbudding/ desuckering	0	
Shoot crushing	0	0

Harvest		
	Fuel consumption L/ha	Hours/ha
Harvest	71.11	1.78
Transport	2.03	0.04

Total fuel (L/ha)	181.75
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## Phytosanitary products

Insecticides/ Fungicides		Emissions to AIR	Emissions to WATER
molecules	quantity (g/ha)	quantity (g/ha)	quantity (g/ha)
folpel	3200	1700.03	1499.97
Fosétyl Aluminium	2000	887.38	1112.62
dinocap	97.5	49.50	48.00
myclobutanil	22.5	10.61	11.89
Bifenthrine	20	10.15	9.85
Tébufenpyrad	50	25.38	24.62
azoxystrobine	187	82.97	104.03
Bore (B)	79.8	37.64	42.16
Molybdène(Mo)	0.9	0.42	0.48
Flufénoxuron	40	17.25	22.75
Tebuconazole	100	49.21	50.79
Diméthomorphe	226	111.22	114.78
Lambda cyhalothrine	13	7.42	5.58
sulphur	70000	33834.65	36165.35

Emissions from Herbicides	
quantity (g/ha) in AIR	quantity (g/ha) in SOL
0	0



## Fertilisation

Fertiliser	kg/ha
-	
Compost (orga 3)	907

P / K emissions to water	
	(Kg/ha)
P2O5	0.2640
K	0

## Nitrogenous emissions

N_volat	1.95	Kg N_NH3	AIR
N_Denit	0.32	Kg N_N2O	AIR
N_Leach	1.77	Kg N_NO3-	WATER

## Grape production

Yield (Kg/ plot)	2443
Yield (Ton/ ha)	5.64

## P80 2006

### Equipment

Soil management		
	Fuel consumption L/ha	Hours/ha
In-row superficial tillage	38.00	4.00
Intercep tillage/ mechanical weeding	40.00	2.67
tillage	0.00	0.00
stone crushing	0.00	0.00

Canopy management		
	Fuel consumption L/ha	Hours/ha
pre-pruning	0.00	0.00
trimming	24.24	2.13
vine lifting	0.00	0.00
disbudding/ desuckering	0.00	0.00
Shoot crusing	12.44	1.33

Fertilisation		
	Fuel consumption L/ha	Hours/ha
fertilisation	3.20	0.36

Harvest		
	Fuel consumption L/ha	Hours/ha
Harvest	71.11	1.78
Transport	1.82	0.04

Pesticide Spraying		
	Fuel consumption L/ha	Hours/ha
Pesticide/Foliar fertiliser spraying	44.92	3.11
Chemical weeding	0.00	0.00

Total fuel consumption (L/ha)	235.71
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## Phytosanitary products

Emissions from Insecticides/ Fungicides			
molecules	quantity (g/ha)	Emissions to AIR (g/ha)	Emissions to WATER (g/ha)
Bifenthrine (g/L)	20	10.15	9.85
Tébufenpyrad (g/L)	50	25.38	24.62
dinocap (g/L)	97.5		
		49.50	48.00
myclobutanil (g/L)	22.5	10.61	11.89
folpel (g/kg)	3250	2292.48	1857.52
Fosétyl Aluminium (g/kg)	1200	532.4	667.57
Bore (B) : 26.6 g/L	159.6	76.91	82.69
Molybdène (Mo) : 0.30 g/L	1.8	0.87	0.93
Tebuconazole (g/L)	100	49.2	50.79
Diméthomorphe (11.3%)	226	111.2	114.78
azoxystrobine (g/L)	187	80.6	106.37
indoxacarbe (30% ou 150g/L)	37.5		
		18.5	19.05
Lambda cyhalothrine (g/L)	12.5	7.13	5.37
Sulphur	43050	6569.9	6780.1
Copper from copper sulfide (15%)	450	221.4	228.5
Copper from copper hydroxyde (g/L)	1548	761.8	786.2

Emissions from Herbicides		
	quantity (g/ha) in AIR	quantity (g/ha) in SOL
glyphozate (g/L)	0	0
sulfate d'ammonium (g/L)	0	0

## Fertilisation

Fertiliser	kg/ha
-	
Compost (orga 3)	907

P / K emissions to water	
	(Kg/ha)
P2O5	0.26
K	0

## Nitrogenous emissions

N_volat	1.95	Kg N_NH3	AIR
N_Denit	0.32	Kg N_N2O	AIR
N_Lessiv	2.07	Kg N_NO3-	WATER

## Grape production

Yield (Kg/ plot)	2193
Yield (Ton/ ha)	5.06

P 80 2008

## Equipment

Soil management		
	Fuel consumption L/ha	Hours/ha
In-row superficial tillage	25.33	2.67
Intercep tillage/ mechanical weeding	0.00	0.00
tillage	0.00	0.00
stone crushing	0.00	0.00

Canopy management		
	Fuel consumption L/ha	Hours/ha
pre-pruning	0.00	0.00
trimming	12.12	1.07
vine lifting	0.00	0.00
disbudding/ desuckering	24.00	2.67
Shoot crushing	0.00	0.00

Fertilisation		
	Fuel consumption L/ha	Hours/ha
fertilisation	0.00	0.00

Harvest		
	Fuel consumption L/ha	Hours/ha
Harvest	71.11	1.78
Transport	0.37	0.04

Pesticide Spraying		
	Fuel consumption L/ha	Hours/ha
Pesticide/Foliar fertiliser spraying	44.92	3.11
Chemical weeding	6.00	0.67

total fuel consumption (L/ha)	185.29
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## Phytosanitary products

Insecticides/fungicides			
molecules	quantity (g/ha)	quantity (g/ha) in AIR	quantity (g/ha) in SOL
Tebuconazole (g/L)	200	94.33	105.67
fosétyl aluminium (g/kg)	1884	835.91	1048.09
métirame zinc (g/kg)	1320	670.10	649.90
Folpel (60%)	2200	1116.83	1083.17
Diméthomorphe (11.3%)	226	106.59	119.41
ferchélate (13%)	91	42.92	48.08
Bifenthrine (g/L)	20	10.15	9.85
Tébufenpyrad (g/L)	50	25.38	24.62
azoxystrobine (g/L)	187	82.97	104.03
sulphur (g/L)	45150	22219.7	22930.31
Copper from copper hydroxyde (g/L)	1548	761.82	786.18
indoxacarbe (30% ou 150g/L)	37.5	18.45	19.05

Herbicides		
	quantity (g/ha) in SOIL	quantity (g/ha) in AIR
glyphozate (g/L)	2000	0
sulfate d'ammonium (g/L)	2300	0

## Fertilisation

Fertiliser	kg/ha
Compost (orga 3)	907

P / K emissions to water	
	(Kg/ha)
P2O5	0.26
K	0

## Nitrogenous emissions

N_volat	1.95	Kg N_NH3	AIR
N_Denit	0.32	Kg N_N2O	AIR
N_Lessiv	0.26	Kg N_NO3-	WATER

## Grape production

Yield (Kg/ plot)	445
Yield (Ton/ ha)	1.027

P 22 2006

## Equipment

Soil management		
	Fuel consumption L/ha	Hours/ha
In-row superficial tillage	15.20	1.60
Intercep tillage/ mechanical weeding	0.00	0.00
Tillage	13.98	0.96
stone crushing	0.00	0.00

Fertilisation		
	Fuel consumption L/ha	Hours/ha
fertilisation	2.40	0.27

Pesticide Spraying		
	Fuel consumption L/ha	Hours/ha
Pesticide/Foliar fertiliser spraying	26.95	1.87
Chemical weeding	4.32	0.48

Canopy management		
	Fuel consumption L/ha	Hours/ha
pre-pruning	21.82	0.96
trimming	26.18	1.37
vine lifting	10.47	0.96
disbudding/ desuckering	0.00	0.00
Shoot crusinging	0.00	0.00

Harvest		
	Fuel consumption L/ha	Hours/ha
Harvest	38.40	0.96
Transport	1.34	0.02

total fuel consumption (L/ha)	160.47
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## Phytosanitary products

Insecticides/ fungicides			
molecules	quantity (g/ha)	quantity (g/ha) in AIR	quantity (g/ha) in SOIL
Bifenthrine (g/L)	20	10.15	9.85
Tébufenpyrad (g/L)	50	25.38	24.62
dinocap (g/L)	97.5	49.50	48.00
myclobutanil (g/L)	22.5	10.61	11.89
folpel (g/kg)	4150	2153.97	1996.03
Fosétyl Aluminium (g/kg)	1200	532.43	667.57
Crème d'algues GA 14	0	0.00	0.00
Bore (B) : 26.6 g/L	79.8	37.64	42.16
Molybdène (Mo) : 0.30 g/L	0.9	0.42	0.48
Tebuconazole (g/L)	100	47.16	52.84
Diméthomorphe (11.3%)	226	106.59	119.41
azoxystrobine (g/L)	187	82.97	104.03
sulphur	43350	20719.37	22630.63
Flufénoxuron (g/L)	40	17.25	22.75
Lambda cyhalothrine (g/L)	12.5	7.13	5.37
Copper from copper sulphate (15%)	450	221.46	228.54
Copper from copper hydroxyde (g/L)	1548	761.82	786.18
indoxacarbe (30% ou 150g/L)	37.5	18.45	19.05

## Herbicides

molecules	quantity (g/ha) in SOIL	quantity (g/ha) in AIR
flumioxazine (50%)	200	0
glyphosate (g/L)	1796.625	0

## Fertilisation

Fertiliser	kg/ha
Compost (orga 3)	1000

P / K emissions to water	
	(Kg/ha)
P2O5	0.266
K	0

## Nitrogenous emissions

N_volat	2.05	Kg N_NH3	AIR
N_Denit	0.35	Kg N_N2O	AIR
N_Lessiv	37.3	Kg N_NO3-	WA TER

## Grape production

Yield (Kg/ plot)	11635
Yield (Ton/ ha)	8.91

## P103 2006

### Equipment

Soil management		
	Fuel consumption L/ha	Hours/ha
In-row superficial tillage	16.89	1.78
Intercep tillage/ mechanical weeding	40.00	2.67
tillage	15.53	1.07
stone crushing	0.00	0.00

Canopy management		
	Fuel consumption L/ha	Hours/ha
pre-pruning	0.00	0.00
trimming	0.00	0.00
vine lifting	11.64	1.07
disbudding/ desuckering	0.00	0.00
Shoot crusing	0.00	0.00

Fertilisation		
	Fuel consumption L/ha	Hours/ha
Fertilisation	2.67	0.30

Harvest		
	Fuel consumption L/ha	Hours/ha
Harvest	42.67	1.07
transport	4.32	0.108

Pesticide Spraying		
	Fuel consumption L/ha	Hours/ha
Pesticide/Foliar fertiliser spraying	29.95	2.07
Chemical weeding	0.00	0.00

Total fuel consumption (L/ha)	164.21
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## Phytosanitary products

Insecticides / fungicides			
molecules	quantity (g/ha)	quantity (g/ha) in AIR	quantity (g/ha) in SOIL
Bifenthrine (g/L)	20	10.15	9.8
Tébufenpyrad (g/L)	50	25.38	24.6
dinocap (g/L)	97.5	49.50	48
myclobutanil (g/L)	22.5	10.61	11.89
folpel (g/kg)	4150	2153.97	590.8
Fosétyl Aluminium (g/kg)	1200	532.4 3	667.6
Crème d'algues GA 14	0	0.00	0
Bore (B) : 26.6 g/L	79.8	37.64	42.16
Molybdène (Mo) : 0.30 g/L	0.9	0.42	0.47
Tebuconazole (g/L)	100	47.16	52.83
Diméthomorphe (11.3%)	226	106.59	119.41
azoxystrobine (g/L)	187	82.97	104.03
sulphur	43350	21333.8	22016.14
Flufénoxuron (g/L)	40	17.25	22.75
Lambda cyhalothrine (g/L)	12.5	7.13	5.36
Copper from copper sulphate (15%)	450	221.46	228.54
Copper from copper hydroxyde (g/L)	1548	761.82	786.18
indoxacarbe (30% ou 150g/L)	37.5	18.45	19.04

Herbicides		
	quantity (g/ha) in AIR	quantity (g/ha) in SOIL
glyphozate (g/L)	0	0
sulfate d'ammonium (g/L)	0	0

## Fertilisation

Fertiliser	
-	
700	kg/ha
700	kg/ha

P / K Emissions to water	
	(Kg/ha)
P2O5	0.25
K	0

### Nitrogenous emissions

N_volat	1.71	Kg N_NH3	AIR
N_Denit	0.26	Kg N_N2O	AIR
			WA
N_Lessiv	14.68	Kg N_NO3-	TER

### Grape production

Yield (Kg/ plot)	890.5
Yield (Ton/ ha)	4.435

**Supplementary data S3: LCIA by work type for the 5 plots under study**

SimaPro 7.3                      Impact assessment

Calculation:                      Analyse  
 Results:                              Impact assessment  
 Product:                              1 kg grape  
 Method:                              Recipe Midpoint (H) V1.07 / World ReCiPe H  
 Indicator:                            Characterisation  
 Unit:                                    %  
 Skip categories:                    Never  
 Exclude infrastructure processes: No  
 Exclude long-term emissions:    No  
 Sorted on item:                    Impact category  
 Sort order:                            Ascending

**P80 2004**                      Yield (Kg/ha) =                      5640

Impact category	Unit	Total	Canopy		Phytosanitary treatments	Fertilization	Harvest
			Soil Management	management			
Climate change	kg CO2 eq	0.224070888	0.028369835	0.021469066	0.034202789	0.097022311	0.043006887
Ozone depletion	kg CFC-11 eq	1.9051E-08	3.23865E-09	2.65995E-09	6.92825E-09	9.447E-10	5.27946E-09
Terrestrial acidification	kg SO2 eq	0.001627796	6.41357E-05	4.29058E-05	0.000145187	0.001291173	8.43952E-05
Freshwater eutrophication	kg P eq	3.79788E-05	4.94444E-06	2.10695E-06	1.0855E-05	1.64689E-05	3.60357E-06
Marine eutrophication	kg N eq	0.000143752	1.91358E-06	9.59012E-07	1.41978E-05	0.000124863	1.81814E-06
Human toxicity	kg 1,4-DB eq	0.025190793	0.00574444	0.002805553	0.01095308	0.001258358	0.004429363
Photochemical oxidant formation	kg NMVOC	0.000396297	6.17824E-05	3.29292E-05	0.000125642	0.000115849	6.00943E-05
Particulate matter formation	kg PM10 eq	0.000355768	3.93752E-05	2.28253E-05	6.27384E-05	0.000185728	4.51018E-05
Terrestrial ecotoxicity	kg 1,4-DB eq	0.005763303	2.57761E-06	1.99543E-06	0.005754029	7.38054E-07	3.96328E-06
Freshwater ecotoxicity	kg 1,4-DB eq	0.002370839	0.00016192	5.46911E-05	0.00203672	2.36721E-05	9.38366E-05
Marine ecotoxicity	kg 1,4-DB eq	0.003442656	0.000174301	6.19956E-05	0.003074578	2.48978E-05	0.000106883
Ionising radiation	kg U235 eq	0.016303126	0.003962422	0.001568389	0.005982633	0.002054328	0.002735354
Agricultural land occupation	m2a	0.115611006	0.000186315	7.52604E-05	0.114145821	0.001081985	0.000121625
Urban land occupation	m2a	0.002347859	9.16275E-05	4.81757E-05	0.002019063	9.59948E-05	9.29982E-05
Natural land transformation	m2	6.91843E-05	1.18194E-05	1.01296E-05	2.48775E-05	1.99015E-06	2.03677E-05
Water depletion	m3	0.000931439	8.93688E-05	4.26448E-05	0.000652735	6.77593E-05	7.89314E-05
Metal depletion	kg Fe eq	0.005060247	0.002400844	0.000632292	0.000995097	0.000187449	0.000844564
Fossil depletion	kg oil eq	6.01384E-05	2.07508E-05	5.9366E-06	1.98945E-05	2.49415E-06	1.10623E-05

**P80 2006**                      Yield (Kg/ha) =                      5060

Impact category	Unit	Total	Canopy		Phytosanitary treatments P80	Fertilization P80	Harvest P80 2006
			Soil Management P80 2006	management P80 2006			
Climate change	kg CO2 eq	0.272254075	0.066250761	0.016466574	0.04315397	0.098580498	0.047802272
Ozone depletion	kg CFC-11 eq	2.51591E-08	7.89978E-09	2.02709E-09	8.48854E-09	8.75546E-10	5.8681E-09
Terrestrial acidification	kg SO2 eq	0.001781448	0.000139574	3.30666E-05	0.000187745	0.001327253	9.38083E-05
Freshwater eutrophication	kg P eq	5.92685E-05	8.60016E-06	1.67252E-06	2.71146E-05	1.78751E-05	4.00613E-06
Marine eutrophication	kg N eq	0.000167514	3.61086E-06	7.56963E-07	1.35975E-05	0.000147527	2.02107E-06
Human toxicity	kg 1,4-DB eq	0.065929383	0.010455565	0.002170144	0.047219515	0.00115998	0.004924178
Photochemical oxidant formation	kg NMVOC	0.000442786	0.000119715	2.57677E-05	0.000129993	0.00010051	6.68003E-05
Particulate matter formation	kg PM10 eq	0.000416802	8.02406E-05	1.78503E-05	8.00955E-05	0.000188483	5.01326E-05
Terrestrial ecotoxicity	kg 1,4-DB eq	0.00756982	6.08165E-06	1.5249E-06	0.007557126	6.82443E-07	4.4052E-06
Freshwater ecotoxicity	kg 1,4-DB eq	0.003372037	0.000262073	4.41022E-05	0.002939653	2.18921E-05	0.000104317
Marine ecotoxicity	kg 1,4-DB eq	0.005068615	0.000287153	4.97006E-05	0.004589812	2.31309E-05	0.000118819
Ionising radiation	kg U235 eq	0.019025368	0.006726903	0.001261637	0.006184347	0.001811539	0.003040941
Agricultural land occupation	m2a	0.079823235	0.000316696	6.02488E-05	0.078378154	0.00093292	0.000135216
Urban land occupation	m2a	0.001887446	0.000177963	3.78798E-05	0.001484427	8.38031E-05	0.000103374
Natural land transformation	m2	8.76117E-05	2.96302E-05	7.71261E-06	2.56818E-05	1.94868E-06	2.26383E-05
Water depletion	m3	0.000861356	0.000165459	3.38909E-05	0.000514851	5.94144E-05	8.77409E-05
Metal depletion	kg Fe eq	0.01682017	0.003579957	0.000516575	0.01160464	0.000180014	0.000938984
Fossil depletion	kg oil eq	7.31617E-05	3.20604E-05	5.09592E-06	2.13847E-05	2.32228E-06	1.22984E-05
Urban land occupation	m2a	0.000997084	3.59499E-05	4.92839E-05	0.000832998	4.68301E-05	3.20216E-05
Natural land transformation	m2	3.53861E-05	5.50884E-06	1.04878E-05	1.14239E-05	9.59426E-07	7.00609E-06
Water depletion	m3	0.000417969	3.41027E-05	4.32818E-05	0.000280352	3.30415E-05	2.71918E-05
Metal depletion	kg Fe eq	0.008189322	0.000783506	0.000621571	0.00640209	9.0558E-05	0.000291596
Fossil depletion	kg oil eq	2.83892E-05	7.14313E-06	5.99729E-06	1.02229E-05	1.20889E-06	3.81698E-06

**P 80 2008**                      Yield (Kg/ha) =                      1027

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Impact category	Unit	Total	Canopy management		Phytosanitary treatments P 80	Fertilization P 80	Harvest P 80 2008
			Soil Management P80 2008	P80 2008	2008	2008	
Climate change	kg CO2 eq	0.888759397	0.103895972	0.169013888	0.286280578	0.098678992	0.230889967
Ozone depletion	kg CFC-11 eq	2.094E-07	1.18594E-08	2.09232E-08	1.43087E-07	5.18803E-09	2.8342E-08
Terrestrial acidification	kg SO2 eq	0.009448158	0.000234929	0.000331259	0.001338003	0.007090764	0.000453202
Freshwater eutrophication	kg P eq	0.000318459	1.81223E-05	1.47985E-05	0.000175719	9.04425E-05	1.93762E-05
Marine eutrophication	kg N eq	0.000512603	7.01193E-06	7.16097E-06	0.000141116	0.000347545	9.76886E-06
Human toxicity	kg 1,4-DB eq	0.316484692	0.02105429	0.019282664	0.24542075	0.006910554	0.023816434
Photochemical oxidant formation	kg NMVOC	0.002290212	0.000226378	0.00024626	0.000858528	0.000636209	0.000322837
Particulate matter formation	kg PM10 eq	0.002102892	0.000144247	0.000177284	0.000519186	0.001019966	0.000242208
Terrestrial ecotoxicity	kg 1,4-DB eq	0.031373324	9.43961E-06	1.56432E-05	0.031322911	4.05319E-06	2.12777E-05
Freshwater ecotoxicity	kg 1,4-DB eq	0.018599436	0.000593468	0.000393301	0.016978196	0.000130001	0.000504469
Marine ecotoxicity	kg 1,4-DB eq	0.016878966	0.000638832	0.000447795	0.015081064	0.000136732	0.000574543
Ionising radiation	kg U235 eq	0.104306669	0.014523252	0.011098782	0.052694431	0.011281804	0.0147084
Agricultural land occupation	m2a	0.413890215	0.00068292	0.000521302	0.406089903	0.005941961	0.00065413
Urban land occupation	m2a	0.009796567	0.00033571	0.000369062	0.008065105	0.000527177	0.000499512
Natural land transformation	m2	0.000392186	4.3276E-05	8.03845E-05	0.000148265	1.09294E-05	0.000109331
Water depletion	m3	0.004562148	0.000327482	0.000319432	0.003119029	0.000372115	0.000424089
Metal depletion	kg Fe eq	0.067431312	0.008800757	0.00431886	0.048738291	0.001029418	0.004543985
Fossil depletion	kg oil eq	0.000365045	7.60613E-05	4.34665E-05	0.000172326	1.36972E-05	5.94948E-05

P22 2006

Yield (Kg/ha) = 8910

Impact category	Unit	Total	Canopy management		Phytosanitary treatments P22	Fertilization P22	Harvest P22 2006
			Soil Management P22 2006	P22 2006	2006	2006	
Climate change	kg CO2 eq	0.158786683	0.012594202	0.022167067	0.01777586	0.09145246	0.014797094
Ozone depletion	kg CFC-11 eq	1.05744E-08	1.47961E-09	2.74479E-09	4.07562E-09	4.58108E-10	1.8163E-09
Terrestrial acidification	kg SO2 eq	0.000974336	2.70888E-05	4.39823E-05	9.36243E-05	0.000780591	2.90489E-05
Freshwater eutrophication	kg P eq	3.02907E-05	1.80337E-06	2.08881E-06	1.48077E-05	1.0348E-05	1.24294E-06
Marine eutrophication	kg N eq	0.001004592	7.38044E-07	9.71896E-07	7.52487E-06	0.00099473	6.26367E-07
Human toxicity	kg 1,4-DB eq	0.032972157	0.002136712	0.002756755	0.025940373	0.000610548	0.001527769
Photochemical oxidant formation	kg NMVOC	0.000198774	2.41727E-05	3.33772E-05	6.39761E-05	5.65495E-05	2.0698E-05
Particulate matter formation	kg PM10 eq	0.000203568	1.59665E-05	2.34666E-05	3.83312E-05	0.000110278	1.55252E-05
Terrestrial ecotoxicity	kg 1,4-DB eq	0.004626985	1.15012E-06	2.05667E-06	0.004622056	3.57986E-07	1.36363E-06
Freshwater ecotoxicity	kg 1,4-DB eq	0.001917931	5.59982E-05	5.47225E-05	0.001763371	1.14818E-05	3.23572E-05
Marine ecotoxicity	kg 1,4-DB eq	0.002928825	6.09284E-05	6.21127E-05	0.002756864	1.20706E-05	3.68493E-05
Ionising radiation	kg U235 eq	0.007988459	0.0014284	0.001560046	0.00305528	0.001001202	0.000943531
Agricultural land occupation	m2a	0.04551039	6.71785E-05	7.4275E-05	0.044798503	0.000528466	4.1967E-05
Urban land occupation	m2a	0.000997084	3.59499E-05	4.92839E-05	0.000832998	4.68301E-05	3.20216E-05
Natural land transformation	m2	3.53861E-05	5.50884E-06	1.04878E-05	1.14239E-05	5.9426E-07	7.00609E-06
Water depletion	m3	0.000417969	3.41027E-05	4.32818E-05	0.000280352	3.30415E-05	2.71918E-05
Metal depletion	kg Fe eq	0.008189322	0.000783506	0.000621571	0.00640209	9.0558E-05	0.000291596
Fossil depletion	kg oil eq	2.83892E-05	7.14313E-06	5.99729E-06	1.02229E-05	1.20889E-06	3.81698E-06

P 103 2006

Yield (Kg/ha) = 4435

Impact category	Unit	Total	Canopy management		Phytosanitary treatments P103	Fertilization P 103	Harvest P 103 2006
			Soil Management P103 2006	P103 2006	2006	2006	
Climate change	kg CO2 eq	0.271972292	0.058038241	0.009971054	0.037981789	0.130862797	0.03511841
Ozone depletion	kg CFC-11 eq	2.19526E-08	7.00476E-09	1.22186E-09	8.46749E-09	9.46821E-10	4.31165E-09
Terrestrial acidification	kg SO2 eq	0.001782742	0.000118914	2.15495E-05	0.00019256	0.001380841	6.88773E-05
Freshwater eutrophication	kg P eq	6.12641E-05	6.59111E-06	1.44118E-06	2.99542E-05	2.03451E-05	2.9325E-06
Marine eutrophication	kg N eq	0.000837436	2.90493E-06	5.58021E-07	1.52162E-05	0.000817275	1.482E-06
Human toxicity	kg 1,4-DB eq	0.067259769	0.008087215	0.00193563	0.052373431	0.001258957	0.003604536
Photochemical oxidant formation	kg NMVOC	0.000410827	9.71811E-05	1.87835E-05	0.000131896	0.000113966	4.90005E-05
Particulate matter formation	kg PM10 eq	0.000392066	6.69992E-05	1.15764E-05	7.94285E-05	0.000197257	3.6805E-05
Terrestrial ecotoxicity	kg 1,4-DB eq	0.009296108	5.33389E-06	9.33646E-07	0.009285865	7.39209E-07	3.23627E-06
Freshwater ecotoxicity	kg 1,4-DB eq	0.003878225	0.00019367	3.63272E-05	0.003548131	2.37057E-05	7.63912E-05
Marine ecotoxicity	kg 1,4-DB eq	0.005911366	0.000214218	4.03677E-05	0.005544781	2.49659E-05	8.70333E-05
Ionising radiation	kg U235 eq	0.016744959	0.005118517	0.001076748	0.00629396	0.00202994	0.002225794
Agricultural land occupation	m2a	0.091463722	0.000240124	5.37318E-05	0.090008345	0.001062598	9.89238E-05
Urban land occupation	m2a	0.002020223	0.000145379	2.58141E-05	0.001678573	9.45965E-05	7.58607E-05
Natural land transformation	m2	7.37227E-05	2.65434E-05	4.49096E-06	2.40238E-05	2.02722E-06	1.66373E-05
Water depletion	m3	0.000856042	0.00013229	2.49007E-05	0.000567658	6.68525E-05	6.43412E-05
Metal depletion	kg Fe eq	0.016773623	0.00249561	0.000478339	0.012923581	0.000189751	0.000686342
Fossil depletion	kg oil eq	6.04769E-05	2.361E-05	4.1825E-06	2.11843E-05	2.50243E-06	8.99777E-06