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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**

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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) 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 CO₂ and N₂O 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 N₂O by reducing denitrification (Steenwerth
156 and Belina, 2008; Lee *et al.*, 2009). Steenwerth *et al.* (2010) suggest that soil CO₂ 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 CO₂ 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 N₂O 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 - NH_3 volatilisation occurs first, i.e. during or just after application (Sommer and
190 Hutchings, 2001);
- 191 - N_2O emissions are computed after Brentrup *et al.* (2000) using IPCC emission factors for
192 land-applied N after correction for volatilised NH_3 ;
- 193 - NO_3^- leaching can be computed from the nitrogen budget, after NH_3 and N_2O 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 (NH_3 emission) peaks shortly after application and then quickly
200 declines. Accordingly, our approach assumes that volatilised N derives only from the initial 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 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 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 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 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 N_2O generation are difficult to compute based on mechanistic models, so
215 IPCC guidelines are used for N_2O 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 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 N_2O , NH_3 and leached 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 Ca^{2+} cations in alkaline soils
250 and Al^{3+} or 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 N_2O emissions) and marine eutrophication (via 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 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

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484

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

Name :	# 80	Species :	Vineyard		
Zone :	XXX	Variety :	Syrah		
Area :	0.69 Ha				
Harvest :	2193 kg				
Fertilising	Commercial name	Quantity	N	P	K
28/09/2006 – Fertilisation	Orga 3 (3-2-3)	907 kg	27	18	27
Harvest	Input Name			Quantity	
30/08/2006 –Harvest				2193 kg	
Pesticide spraying	Commercial name	Quantity	Target		
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
Tillage			
03/03/2006 – Harrowing			
24/04/2006 - On-the-row weeding			
16/05/2006 – Harrowing			
17/05/2006 - Interstock tillage			
02/10/2006 – Harrowing			
Canopy management			Output Quantity
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 ³)	1200	1100	1700
Organic matter content (%)	2	1	1
Soil depth (h in mm)	500	300	300
CaCO ₃ (ppt)	100	200	10
% stones	10	50	0

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 ^{a,b}	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 ^a	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

^a The name of inputs are known for each operation but not reported here;

^b 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%)

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

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Table 5: Data required to compile LCI in viticulture; 3rd column relates to “traced data” (X where data is already traced); 4th column relates to pieces of information that must be linked to each name in the name lists which is; columns 5th to 8th 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
OPERATION DATA							
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

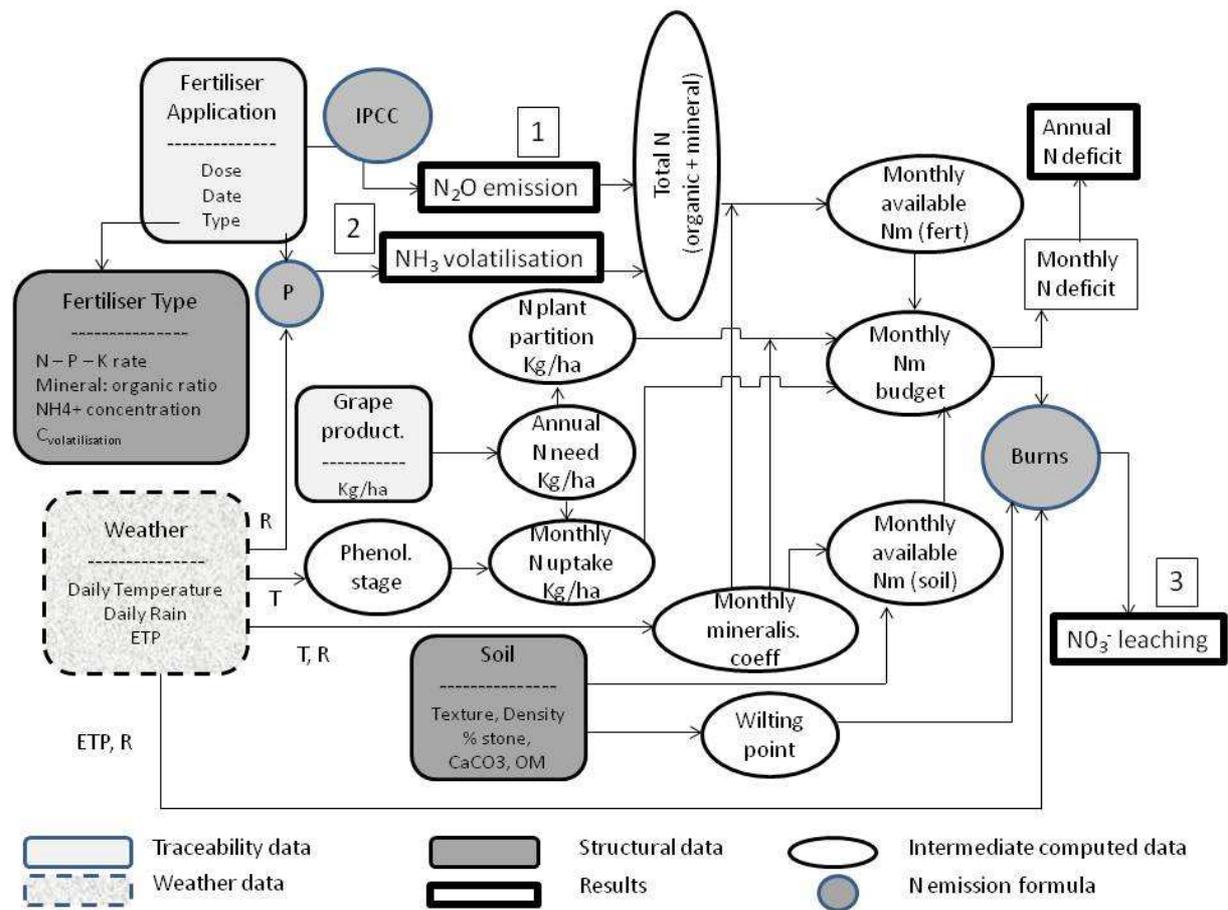
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D	Application date	X				1	1
WEATHER DATA							
P	Daily precipitation					1	2
T	Temperature					1	
PLOT DATA							
IR	Interrow distance*				1		
De	Nb of stocks per ha*	X			1		
Sd	Soil data*		Texture			1	
			Organic matter content			1	
			CaCO ₃ content			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 ₂ eq)		Global Warming Potential (g CO ₂ eq)		Eutrophication Potential (g PO ₄ ²⁻ 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

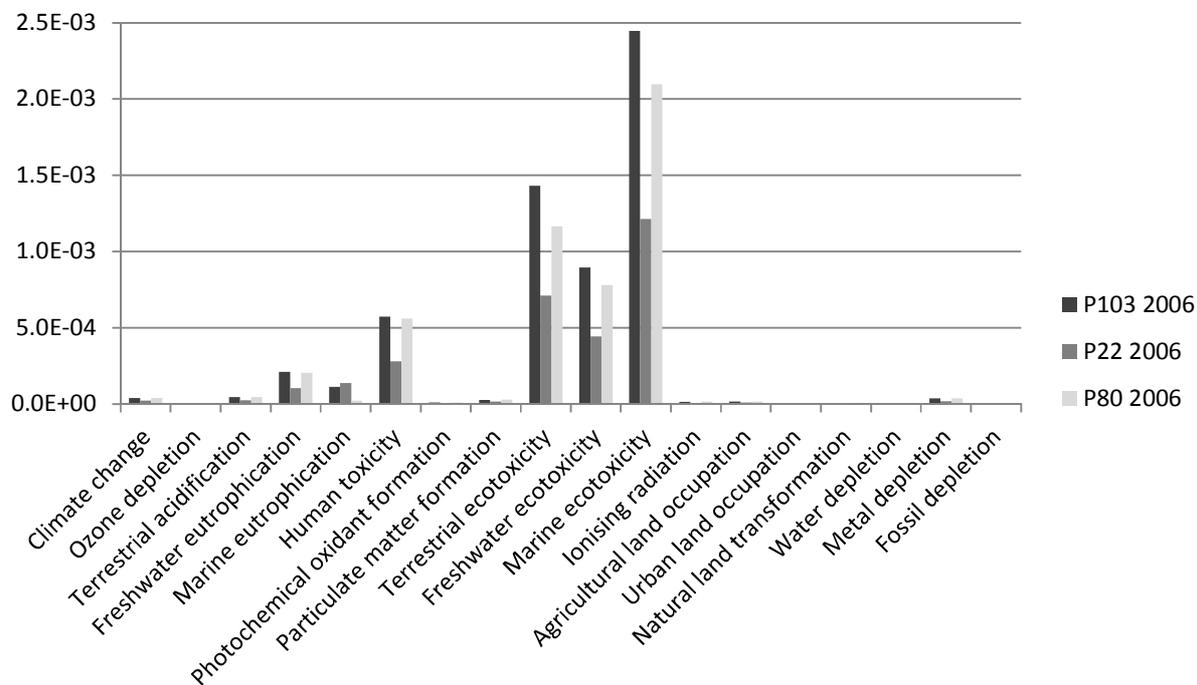
1



2

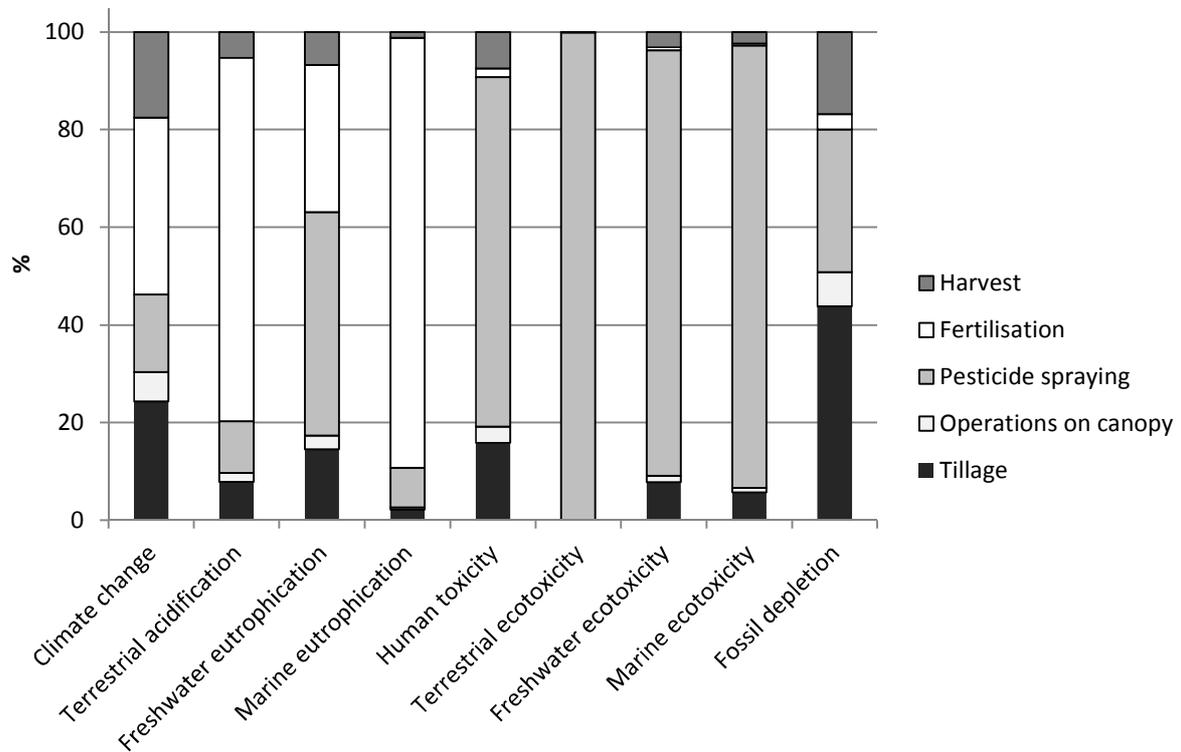
3 Figure 1: Conceptual framework showing how field N emissions are computed based on
 4 traceability, weather and structural data. Figure numbers 1–3 show the order of computation in
 5 the algorithm. P stands for PestLCI formula, R for Rainfall, T for temperature, ETP for
 6 evapotranspiration, OM for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

7



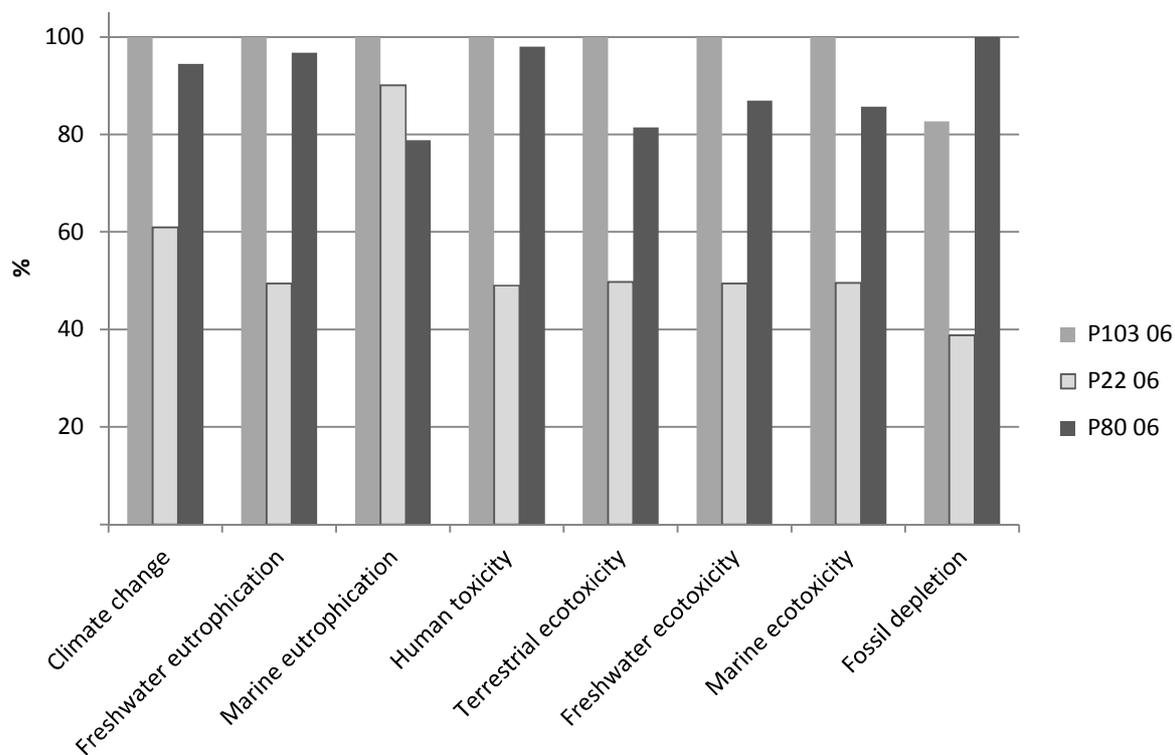
8
9 Figure 2: Normalisation of LCA outputs for 1 kg Syrah grape production grown in three different
10 plots on the same year (ReCiPe Midpoint (H) V1.07 / World ReCiPe H)

11

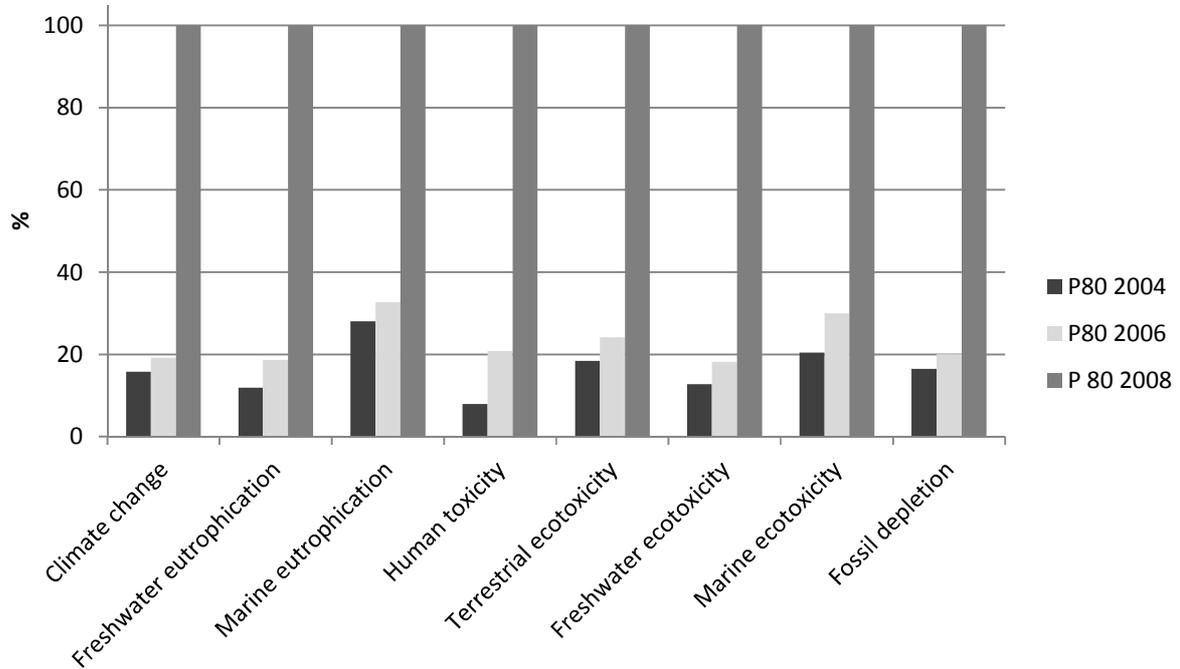


12
13 Figure 3: Contributions of the various viticultural operations to LCIA of grape production (Plot P
14 80 2006; FU = 1 kg grape production; ReCiPe Midpoint (H) V1.07 / World ReCiPe H)

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

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

where N_{NH4+} is the amount of NH_4^+ in the fertiliser input, Cv 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 λ 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 ₃ (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 ³)	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 ₃	DENITRIFIED N Kg N-N ₂ O	LEACHED N Kg N-NO ₃ ⁻	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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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 crusching	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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Phytopsanitary 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 crusing	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 tillage	40.00	2.67
stone crushing	15.53	1.07
	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
N_Lessiv	14.68	Kg N_NO3-	WA
			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