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Energy recovery by anaerobic digestion of organic residues from agroindustry

Pascal LEVASSEUR (1), Laureen BADEY (2), Marie BARTHELEMY (3), Thierry BIOTEAU (4), Yvan DELOCHE (5), Franck JOLIBERT (6), Sophie PENAVAYRE (7), Stéphanie PRASSE (8), Jacques THEBAULT (9), Michel TORRIJOS (10)

(1) IFIP-Institut du Porc, Domaine de la Motte au Vicomte, 35650 LE RHEU
(2) ITERG-11 rue Gaspard Monge - 33610 CANEJAN
(3) AGRIA Grand Est, 2 rue du Doyen Marcel Roubault, 54505 VANDOEUVRE-LES-NANCY
(4) IRSTEA Rennes, 17 avenue de Cucillé, 35044 RENNES cedex
(5) CRITT PACA, 100 rue Pierre Bayle, 84140 MONTFAVET
(6) UNGDA, 174 Boulebard Camélinat, 92247 MALAKOFF
(7) IFV, 210 Boulevard Vermorel, 69660 VILLEFRANCHE SUR SAÔNE
(8) CTP, Domaine universitaire, 38044 GRENOBLE
(9) IPC, 125 rue Aristide Briand, 92300 LEVALLOIS PERRET
(10) INRA LBE, 102 Avenue des étangs, 11100 NARBONNE

pascal.levasseur@ifip.asso.fr

Supported by earlier collected data, the partners in the Valormap project made a resource inventory of potentially methanizable by-products in each of their respective industrial sectors. This survey also enabled production ratios to be determined or updated, and by-products to be sampled for analysis. The biochemical methane potential and levels of dry and organic matter, ammoniacal and total nitrogen, phosphorus and potassium were determined in more than 90 waste products generated by the agrifood industry. The project participants drew up over twenty 'by-product' data sheets giving essential information. For the main categories of organic waste identified in this project, a public web tool gives access to corresponding mass by administrative district, and corresponding amount of recoverable energy in kWh and Nm^3 CH_4, by subdistrict. All these results can be found on the project website https://www.valormap.fr/.

Valorisation énergétique par méthanisation des résidus organiques des agro-industries

Après avoir capitalisé des données antérieures, les partenaires du projet Valormap ont procédé à une étude de gisement des co-produits potentiellement intéressants pour la méthanisation au sein de leurs filières respectives. Cette enquête a permis en outre d'établir ou de réactualiser des ratios de production et d'échantillonner ces co-produits à des fins d'analyse. Le potentiel méthanogène et les concentrations en matières sèches et organiques, azotes ammoniacal et total, phosphore et potassium ont ainsi été déterminés sur plus de 90 déchets des industries agro-alimentaires. Les auteurs du projet ont réalisé plus d'une vingtaine de fiches « co-produits » où figurent les informations essentielles les concernant. Pour les grandes catégories de déchets organiques identifiés dans ce projet, un outil web public donne accès aux masses correspondantes à l'échelle départementale et aux quantités d'énergie correspondantes, sous forme de KWh et de Nm^3 CH_4, à l'échelle cantonale. L'ensemble des résultats sont disponibles sur le site du projet (https://www.valormap.fr/).

Mots clés : organic residue, anaerobic digestion, resource, geolocation
Keywords: résidu organique, méthanisation, gisement, géolocalisation

Introduction

In France, one fast-growing way to gainfully process organic matter is anaerobic digestion. Agroindustry generates large amounts of organic residues offering potentially high methane yields through recovery by anaerobic codigestion. The aim of the ValorMap project was to set up a geographical database on energy recovery by anaerobic digestion of organic residues and by-products from agroindustry. This project brought together (i) technical institutes covering several agroindustry sectors (pig industry, fats, alcohol production, papermaking and winemaking), (ii) Regional Centers for Innovation and Technology Transfer (CRITT) in several regions (Provence Alpes-Côte-d'Azur, AGRIA Grand Est, and IPC) and (iii) two publicly funded research centers: the Environmental Biotechnology Laboratory (LBE) at INRA Narbonne, and IRSTEA Rennes.

***Table 1.** Annual production of organic residues and by-products identified by the Valormap project **

Geographical scale	Sector concerned	Identified by-product or residue	Annual resource
PACA Region	Olive oil sector	Olive pomace	4 756 t DM
	Meat sector	By-products (mixture)	11 055 t
	Fruits and vegetables sector	Organic residues (mixture)	103 334 t
Former Lorraine Region	Milk and cheese sector	Whey	560 491 m^3
		White waters	2 511 180 m^3
		Cheese waste	451 t
	Meat sector	By-products (category 2-3)	1 365 t
		Stercoral matter	6 802 t
	Industrial breadmaking and pastry sector	Waste from pastry and finished products (mixture)	14 523 t
Former Auvergne Region	Milk and cheese sector	Cheese	90 380 t
		Whey	576 740 m^3
		White waters	1 153 830 m^3
	Cereals sector	Milling by-products	28 952 t
National	Pork sector	Sieve residue	21 264 t
		Flotation greases	13 262 t
		Sludges	7 914 t DM
	Winemaking sector	White grape distillates	422 892 t
		Red and rosé grape distillates	491 171 t
		Wine lees	144 325 m^3
	Alcohol distilleries (grape fermentation)	De-alcoholized distillates (grape fermentation)	360 000 t
		Distillery residues (grape fermentation)	500 000 t
	Alcohol distilleries (fruit fermentation)	Pear distillates	200 – 2000 t
		Plant wastes	200 t
		Apple distillates	4 000 t
		Bottom lees	300 t
		Apple distillate residues	15 000 m^3
	Alcohol distilleries (agricultural)	Beetroot pulp	491 680 t
		Dried grains	820 725 t
	Papermaking sector	Mixed sludges	210 t DM
		De-inking sludges	303 t DM
	Fats sector	Waste from grain sorting	84 025 t
		Bottoms	6 400 t
		Neutralization mix	17 500 t
		Acidic oils	39 500 t
		Spent bleaching clays	6 825 t
		Spent winterization earths	1 500 t
		Deodorization condensate or fatty acid distillate	2 600 t
		Fats from margarine production	1 000 t

** Units of measurement differ according to usage. The tonnages provided are for raw matter except for certain biowastes quantified in tons of dry matter (stated in the table).*

Agroindustry organic residues as a resource

One of the Valormap project's first tasks was to assess the resources inherent in organic residues and by-products throughout France, and to evaluate how readily they could undergo anaerobic digestion, according to their strengths and weaknesses (methanogenic potential, competing recovery sectors, health and safety status, etc.). Each technical institute and regional center could choose their own survey methods – questioning by telephone and/or on-site, use of statistical databases, bibliographies, expert consultations, etc.

Resources in the form of solid residues identified by the Valormap project amounted to about 3.5 million tons of raw matter. The project also found 5 million m^3 of liquid residues and 13,000 tons of dry matter in other biowaste, in particular biological sludges. The nature of these organic by-products and residues is detailed in the report of the resource study retrievable at the project website (https://www.valormap.fr/). These resources are volumes generated, not volumes of residues available for anaerobic digestion. White waters made up 74% of the liquid resources identified by the project. These have no utility for methane production but could be used to dilute too-dry feedstock mixtures. Table 1 sets out the main resources identified by the project.
So that the database could be updated at a later date, one of the project's aims was also to estimate residue production ratios based on easily accessible variables (size of workforce, tonnage of feedstock processed, etc.). It was found that some ratios were fragile and required caution in use because they greatly depended on the type of operator and the practices in use. This aspect is discussed in particular in the deliverable that can be retrieved on the project website.

Chemical composition and biochemical methane potential (BMP)

During the resource assessment, the partners in the Valormap project took more than 90 samples of organic residues for physical and chemical characterization and measurement of biochemical methane potential (BMP). BMP estimates were made at the LBE at INRA Narbonne, where most of the physical and chemical analyses were also carried out. To present the results cogently the samples analyzed were grouped into 10 categories (see Table 2). This table gives average concentrations of dry matter (DM) and organic matter (OM) for these 10 residue categories. The residues in categories 7 and 8 were dilute, with average OM/DM ratios below 9%. By contrast, this ratio was on average above 45% for categories 6, 3, and 4.

Nitrogen and phosphorus contents ranged widely between residue categories. The impact of feedstock mixtures on nitrogen concentration needs to be evaluated to prevent inhibition of methane production in the digester. Animal and plant residues from agrifood processing (categories 4 and 6), and papermaking sludges (category 1) can present very high nitrogen concentrations. However, levels ranged widely here within each of these categories.

Plant residues from agrifood processing (category 4), winemaking by-products and alcohol distillery waste (category 5), and residues from milk and cheese production (category 7) presented the highest average concentrations of potassium, but like for nitrogen and phosphorus, showed wide variability within categories (values available on the project website).

***Table 2.** Physical and chemical analysis results, methane potential and yield of residues sampled in the Valormap project **

	Eff.	DM	OM	BMP	MY	N	P	K
	n	% RM	% DM	ml CH_4/ g OM	m^3 CH_4/t RM	g/kg RM		
1- Sludges from papermaking	7	36	31	208	42	10.4	6.3	0.8
2- Fruits, vegetables and residues of fruits and vegetables from food processing	10	24	19	321	71	6.4	2.2	2.4
3- Residues from refining of plant oils and margarine production	15	72	55	495	294	2.2	3.0	0
4- Plant residues from food processing	12	80	73	344	261	15.9	8.8	8.4
5- By-products from winemaking and alcohol distilleries	35	29	22	245	59	6.8	1.7	8.1
6- Animal residues from food processing	5	54	47	660	315	23.8	15.9	1.6
7- Residues from milk and cheese production	5	8	6	433	28	3.1	1.9	7.0
8- Sludges from water treatment at agrifood sites	4	10	8	192	13	6.1	4.2	0.6
9- Residues from effluent defatting at agrifood sites	6	32	28	647	231	2.5	0.9	0.1
10- Residues from phase separation of slaughterhouse effluent	3	30	25	409	120	8.5	2.0	0.4

***Eff: effective - RM: raw matter - DM: dry matter - OM: organic matter - MY: methane yield - BMP: biochemical methane potential – Phosphorus as P, not P_2O_5 - Potassium as K, not K_2O*

BMP depends on the biodegradability of the organic matter in the residue considered. It is expressed in ml CH_4/ g of OM. Table 2 shows that categories 8, 1 and 5 had rather low average BMP, suggesting that their biodegradability is moderate and that a large fraction of the solids in the residues belonging to these categories will not be degraded during anaerobic digestion. Three categories had average BMP values greater than or equal to 500 owing to the presence of fats in their residues.

Methane yield is the volume of methane that can be produced per ton of raw matter (RM). It is expressed in Nm^3 of CH_4/t RM. This variable is important for assessing energy recoverability by the anaerobic digestion of residues. Industrial operators use it to calculate the amount of methane produced by a anaerobic digestion unit. Methane yield takes into account both the BMP and the organic matter content of the residue. Figure 1 shows average methane yields for all 10 categories. Overall, five categories (8, 7, 1, 5 and 2) had low or moderate methane yields, with average values below 80 Nm^3 CH_4/t RM. Four categories (9, 4, 3, 6) had very high methane yields with average values above 200 m^3 CH_4/t RM. We emphasize that standard deviations were very high for almost all the categories (Figure 1), reflecting very high variability within categories.

Specific data can be downloaded from the project website (https://www.valormap.fr/) in MS Word® format to implement the existing databases belonging to the different anaerobic digestion actors (farmers running anaerobic digestion plants, energy/environment advisors, design engineers, constructors, public authorities, etc.).

Individual datasets for these 90 residues were compiled with results obtained earlier and those in the updated MéthaSim (*) database. This data repository thus provides values of methanogenic potential, dry and organic matter content (and nitrogen, phosphorus and potassium content in very many cases) for more than 400 organic residues: animal waste, crops and their residues, and organic waste from agroindustry and local community operators. The file can be downloaded from the IFIP website (http://bit.ly/BD-metha) in MS Excel® format.

Organic residue datasheets

The project partners have drawn up some twenty 'by-product' datasheets, which are available on the project website. They support a first exchange with anaerobic digestion plant operators to evaluate the potential utility of different by-products for anaerobic digestion.

The datasheets, 4–5 pages long, are downloadable from the project website. They contain the following information:

- **Description of the residue.** This includes methods for obtaining it and its nature. The aim is to be able to identify biowastes despite different designations. The physical and chemical composition (dry and organic matter, total and ammoniacal nitrogen, phosphorus and potassium) is also stated.
- **Quantities and location of the resources.** Based on resource surveys, this part reports main production ratios, quantities produced nationally or regionally, and main location features (scattered resources, or conversely resources concentrated at certain sites or in certain geographical areas).

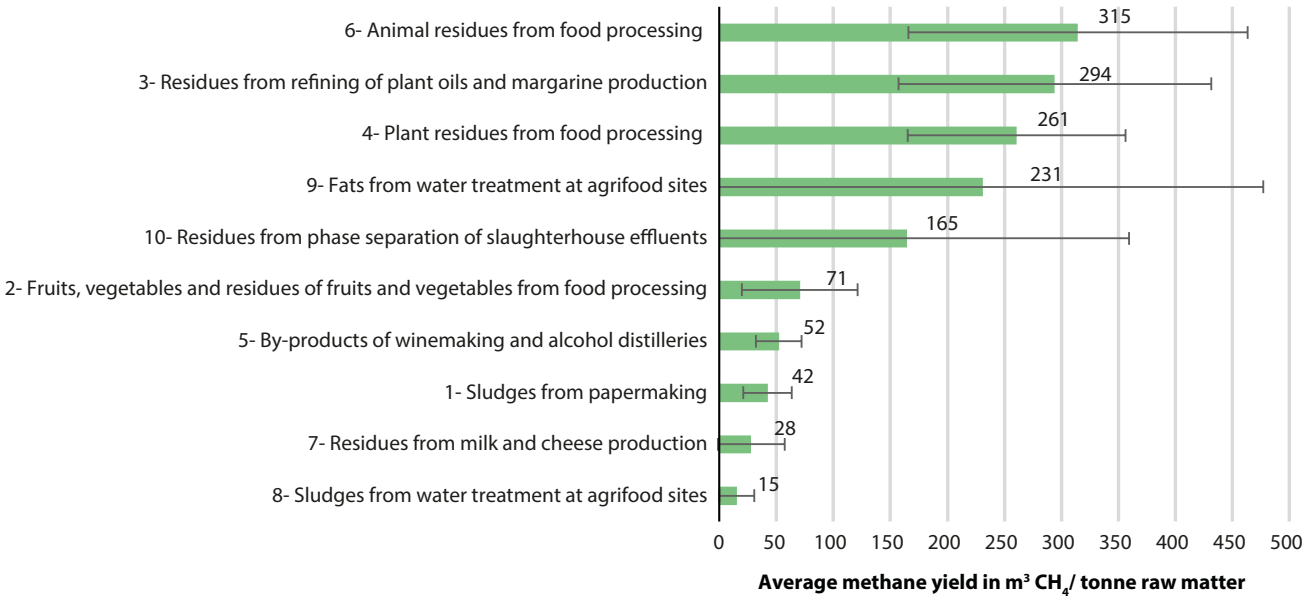


Figure 1. *Average methane yields and standard deviations in 10 families of organic residues*

(*) MéthaSim is an IFIP web tool designed to simulate the extent and economic value of farm-based anaerobic digestion projects (https://methasim.ifip.asso.fr). The most recent version (2018) integrates the latest prices of electricity from a anaerobic digestion unit. Besides updating investment and operating costs, this calculator will now simulate the economic value of biomethane injection and compare it with that of electricity production by co-generation. This calculator also provides an initial approach to costing digestate treatment. Users are charged for this new version to help pay for maintenance of the tool. Further information can be found on the IFIP website.

- **Scope for energy recovery by anaerobic digestion.** Methane potentials and yields as determined in the project are set out in this part. They are discussed and compared with other families of waste.
- **Points needing special attention.** The residue may be foul-smelling, contain undesirable components, be already gainfully reprocessed elsewhere, be seasonal, etc. All such specific features or drawbacks need to be known before making recovery plans for a residue.
- **Tabular overview of strengths and weaknesses.** This part recapitulates the main information already given. In conclusion, the author of the datasheet scores the residues on a probable recoverability scale in the light of the strengths and weaknesses outlined. .

Web tool for the geolocation of organic residues

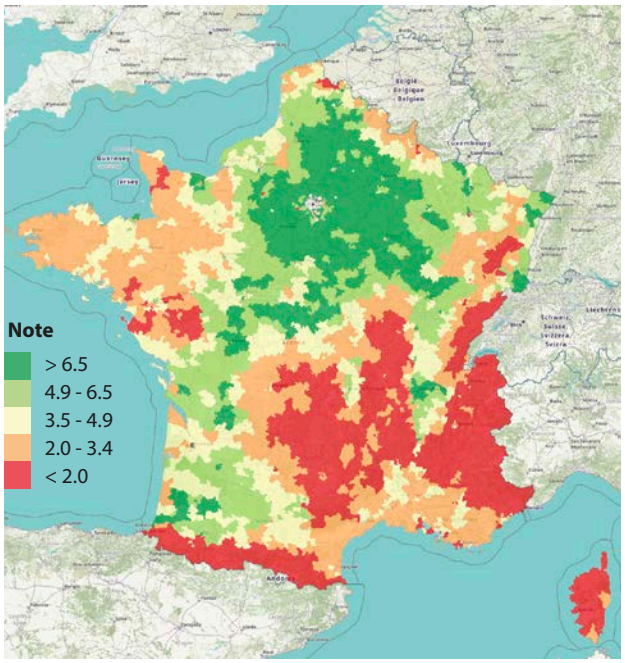
The project's findings also enable all these recoverable waste resources to be geolocated. A public web tool gives access to the major categories of waste by administrative district, and to corresponding energy quantities in both kWh and Nm^3 CH_4 by subdistrict. A MS Excel® spreadsheet giving tonnages (or volumes) of all 10 categories of organic residues, together with potential recoverable energy quantities, can be downloaded by administrative district.
The web tool also visualizes the raw production amounts, potentially recoverable waste resources and ground application potential in map form. These maps are interactive, with tick boxes to select or deselect different categories of residue, ground application constraints, etc., as required.

The 'ground application potential' background takes into account four exclusion conditions (slope, flood-

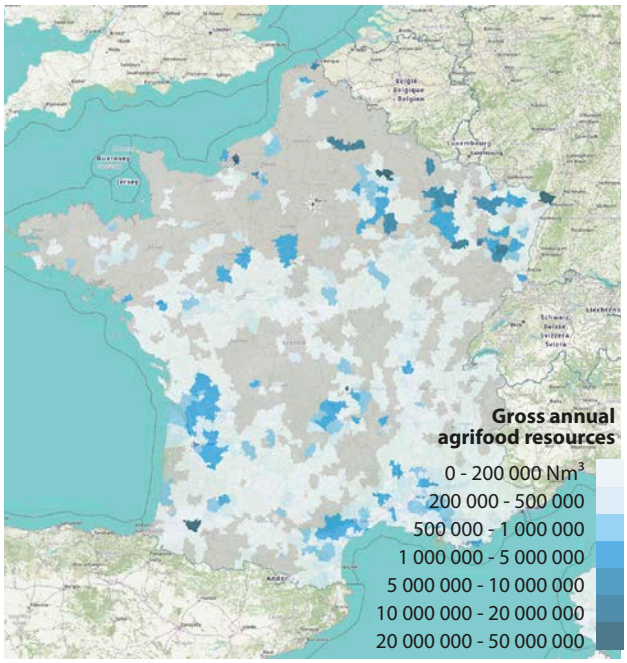
***Table 3.** 'By-product' datasheets drawn up in the Valormap project*

Organic residue family	Corresponding residues (1 residue = 1 datasheet)
1- Sludges from papermaking	• Papermaking sludge
2- Fruits, vegetables and residues of fruits and vegetables from food processing	• By-products of fruits and vegetables
3- Residues from refining of plant oils and margarine production	• Bottoms • Neutralization mixes • Spent earths • Fats from margarine production • Deodorization condensates and fatty acid distillates
4- Plant residues from food processing	• Brewery grains • Olive pomace and liquid waste (production of olive oil) • Flour milling waste
5- By-products from winemaking and alcohol distilleries	• Wine lees • Beetroot pulp • Dry grains (ethanol production) • Grape distillates • Grape distillery residues • By-products of alcohol distilleries (de-alcoholized fruit and grape distillates, lees, other by-products)
6- Animal residues from food processing	• Waste from fresh and cured meat processing
7- Residues from milk and cheese production	• Whey
8- Sludges from water treatment at agrifood sites	• Biological sludge (from pork slaughterhouses)
9- Residues from the defatting of effluents from agrifood sites	• Flotation grease (from pork slaughterhouses)
10- Residues from phase separation of slaughterhouse effluents	• Sieve residues (from pork slaughterhouses)

***Map 1.** Scope for ground application*



***Map 2.** Cumulated energy potential of organic residues*



The web tool at https://www.valormap.fr/?page_id=289 geolocates certain organic residue resources generated by agroindustry.

proneness, distance from buildings < 50 m, and level of crop needs for organic fertilizer) and an indicator of livestock pressure (via all-feed LU values). A final score between 1 and 12 is obtained for each subdistrict, offering a useful **indicator to assist decision-making for future projects.**

Conclusion

Energy recovery by anaerobic digestion of organic by-products and residues from agroindustry was studied in the Valormap project. The project partners identified an annual production of some **3.5 million tons of solid waste and 5 million m³ of liquid waste**, representing a theoretical biomethane production of 509 million Nm³ CH_4/year. The residues identified were not all, or not fully utilizable for anaerobic digestion, owing to various regulatory, technical or economic constraints. Taking an optimistic recoverability rate set by the project partners, annual biomethane production from the available resources would be about **123 million Nm³ CH_4.** The project's main findings are available on its website www.valormap.fr, where an interactive map can be used. This map visualizes, at subdistrict scale, volumes of biomethane that can be produced by the residues studied in the Valormap project, and the potential for ground application of the digestates.

This project did not cover all the French agroindustry sectors, either geographically or in terms of organic residues. The database and map may be extended later as required by professional operators in those sectors and in that of anaerobic digestion. Keeping these tools fully functional after the project has ended will be a further challenge.

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