

## VI.1

# Utilization of waste from food and agriculture

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### VI.1.1. Recycling of organic wastes – one of the major tasks of today's waste management policies

The modern agricultural sector generates great amounts of wastes, which represent a tremendous threat to the environment, and human and animal health. The overall policy that controls utilization of agricultural wastes today is part of the general efforts to reduce the pollution and prevent further deterioration of the environment from all types of wastes. One of the main tasks of today's waste management policies is to reduce the stream of organic waste going to landfills and recycle the organic matter and the plant nutrients back to the soil (Al Seadi, 2001).

The intensive agricultural practice and the utilization of mineral fertilizers, pesticides and pharmaceuticals in agriculture have an increasing impact on the environment and have changed the perception of animal manure and other agricultural by-products from valuable resources to a global waste problem.

Agricultural production has an impact on the atmosphere, the groundwater, rivers, and streams as well as on the landscape, in the same way like non-agricultural activities (Bauder and Vogel, 1989–1990). Environmental pollution is mainly caused by emissions and leaching from different agricultural wastes (manure disposal and spreading, slurry storage and spreading, fertilizer lots and spreading, pesticides spreading and disposal, vegetable mass disposals, etc.). Many types of wastes of agricultural origin can be contaminated with crop and animal diseases, chemical and physical contaminants.

Nevertheless, major steps forward have been made to find better ways of utilization of agricultural wastes, currently included in the larger notion of biomass. Biomass-based renewable energy production is today one of the most attractive ways of utilization and recycling of agricultural wastes and by-products, contributing to the reduction of the emissions of greenhouse gases by displacing fossil fuels and preventing pollution caused by traditional waste disposal. The struggle of reducing the global emission of CO<sub>2</sub> from the fossil fuels-based energy production transformed biomass into a very attractive alternative source of renewable energy. In the 15 EU-countries only, the level of biomass conversion to energy was 44.8 Mtoes (million tons of oil equivalents; 1 toe = 1 × 10<sup>10</sup> cal) in 1999, and the target for year 2010 is 131 Mtoes (Holm-Nielsen and Al Seadi, 1997). The statistical data from the European Commission show that the primary energy production from biomass increased in EU countries by 29% between 1987 and 1997.

The environmental and waste handling and disposal policies and legislation in most European countries are directly or indirectly encouraging the use of biomass for energy production and the recovery of the energy that results from agricultural waste processing (EC DG ENV, 2001).

Finding sustainable solutions for the utilization of agricultural wastes is one of the greatest challenges of the agricultural sector. This also means that agricultural wastes must no longer be regarded as problems but as valuable resources and utilized in a way that provides maximum safety, minimum environmental impact and as far as possible, recyclable end-products (Al Seadi, 2001). Safe recycling of agricultural wastes is an objective of increased public awareness and the quality control of these types of biomass is therefore essential.

### **VI.1.2. Utilization of agricultural wastes: the main streams**

Agricultural utilization/recycling:

- fodder;
- bedding;
- fertilizer:
  - raw materials,
  - digestate from biogas production,
  - compost;
- other agricultural utilization.

Bioenergy production:

- biogas from anaerobic digestion;
- biofuels;
- incineration.

Industrial non-food utilization:

- biocomposite and vegetable fiber boards;
- starch-based biodegradable plastics and polymers;
- thickeners and lubricants;
- lignocellulosic thermoplastics;
- manufacture industry;
- pharmaceuticals and cosmetics;
- biopesticides;
- structure improvers;
- pulp and paper;
- lactic acid;
- waxes;
- other.

Industrial fodder:

- vegetable fodder pellets;
- alcohols and sugars;

- amino acids and proteins;
- other.

Landfilling:

- Recommended only when alternative options are not suitable. Current environmental regulations in EU limit the landfilling of organic wastes, due to its environmental impact and lack of sustainability (EC, 1999).

### **VI.1.3. Animal manure – fertilizer or waste**

The intensive animal production of the industrialized agriculture, widely practiced during the last 40 years, has created serious problems of agricultural waste disposal. Mechanization and the decreasing labor force have required new animal production systems and use of imported feeding stuffs. The modern stable systems transformed manure consistency from solid to slurry (liquid) and the production of slurry exceeded the capacity of the available land for its optimal use. This situation became common throughout the world, from the large cattle feed lots in North America to intensive pig production throughout Europe (Fig. VI.1.1), America and Asia.

The historical development of agriculture shows what a tremendous impact the use of animal manure had on the supply of nutrients to the soil, increasing the volume and improving the quality of the crops. In the old cropping systems, the nutrients contained in the manure were obtained from the same land that produced fodder for the animals. In this way, the improvement of the soil fertility and a loss of fertility due to crop production mainly took place in the same area (Wadman et al., 1987).

The situation has mainly changed today, when the majority of animal production systems, especially in western and northern Europe and USA are no longer land dependent. Animal feeds are produced away from the place of animal production, more and more often abroad. This phenomena happens together with an unprecedented increase in production in Europe livestock and generally in the whole world, as a consequence of several factors such as increased demand for meat/dairy products on the market originating from increased living standard, increased labor productivity, intensive forage production as a consequence of using pesticides and mineral fertilizer in crops production, use of concentrated forages in animal production, improved veterinary control of diseases, larger export markets, etc. (Wadman et al., 1987).

During all this process, the perception of value of animal manure decreased from a valuable natural fertilizer to a waste product due to two main factors. First, the development of intensive animal production, not land dependent, in many regions of Europe and North America, resulted in high livestock density and an excess of manure in these regions. Secondly, during the same period, mineral fertilizers widely replaced manure in the crop production systems, as a much cheaper alternative. This has made manure no longer an indispensable fertilizer for the crops but an unwanted waste product, as the choice between manure and mineral fertilizers depends on their total costs (Wadman et al., 1987).

It is more likely that the composition of animal manure has generally improved during the last century, as the nutrient content in manure depends on the quality and digestibility

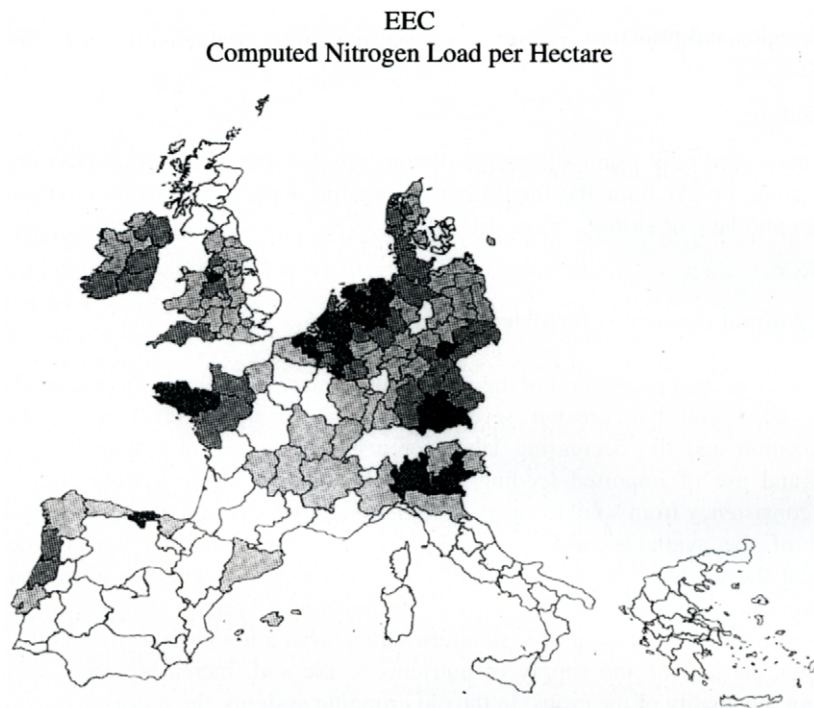


Figure VI.1.1. Manure density (after Danish Energy Agency, 1993).

of the animal feed (Wadman et al., 1987). At the same time, new aspects concerning manure quality appeared, due to the new agricultural practices, such as the use of pesticides, inorganic phosphorous fertilizers or sewage sludge (rich in phosphorous) in fodder production, the use of phosphates in concentrates, as well as due to non-agricultural emissions/pollution. Furthermore, the change of manure consistence from solid to slurry has brought up the necessity of establishing new collection, storage and spreading systems and techniques. The excess of manure production left the farmers with no alternative but the application of high amounts of manure, facing severe environmental problems, or an expensive transfer of the manure in excess to areas in need of organic nutrients. Consequently, regulations and restrictions on manure handling and application were implemented in many countries (storage capacity, amount per hectare, season of application, techniques, etc.), further reducing the value of manure. Consequently, European Community by issuing Council Directive 91/676/EEC (EEC, 1991) also enforced limitations of manure applications in order to protect water resources from pollution caused by nitrates. Industrialized agriculture gradually turned animal manure

from a valuable natural fertilizer into an environmentally problematic waste (Wadman et al., 1987).

#### **VI.1.4. Utilization of animal manure**

Modern utilization of animal manure and slurries requires funding and implies social consequences where the environmental effects, both the pollution potential and the energy potential, should be taken into consideration. It also requires regulation of handling, storage, treatment and application as well as improvement of nutrient efficiency. Manure management problems often arise when livestock are added to a farm without increasing the land base.

One of the main problems of using liquid manure as fertilizer is that costs increase with increased distance of transportation. The methods of transport are various and depend on the system of production and the design of the production unit. Normally the liquid manure (slurry) can be transported in vacuum tankers to and from the storage facilities or it can be piped for shorter distances. With conventional transport facilities, animal manure can counterbalance a transportation distance of approximate 15 km, while concentrated manure can counterbalance longer transport distances. Slurry can be handled and treated in many ways, each with its advantages and disadvantages (see Figure VI.1.2). Treating/concentrating manure is one of the common ways of improving its value, by improving the utilization of nutrients, making it more suitable for transportation and redistribution. Treatment of manure transforms it into an attractive fertilizer for all types of farming and contributes to the achievement of a territorial balance of manure concentration (Gasser, 1984). The main issues related to slurry treatment refers to:

- anaerobic digestion combined with concentration;
- mechanical separation/filtration;
- separation and concentration of nutrients/lagoon evaporation;
- decomposing of organic matter;
- precipitation and flocculation;
- accelerated composting and drainage.

#### **VI.1.5. Nitrogen supply from animal manure**

The composition of animal slurries varies with species, animals' age, and diet (Wadman et al., 1987), while its concentration is affected by the amount of extraneous added water (Gasser, 1984). The difference between cattle, pig and poultry slurry is the proportion of the three macronutrients: nitrogen (N), phosphorus (P) and potassium (K) (Table VI.1.1.). The table shows a higher proportion of K in relation to N in cattle manure while pig and poultry manures are higher in P.

The use of animal slurry as fertilizer can lead to severe pollution problems for the environment in case of inadequate application practice. The most frequent causes of pollution are surface run-off, losses of ammonia and nitrous oxide to the atmosphere, and

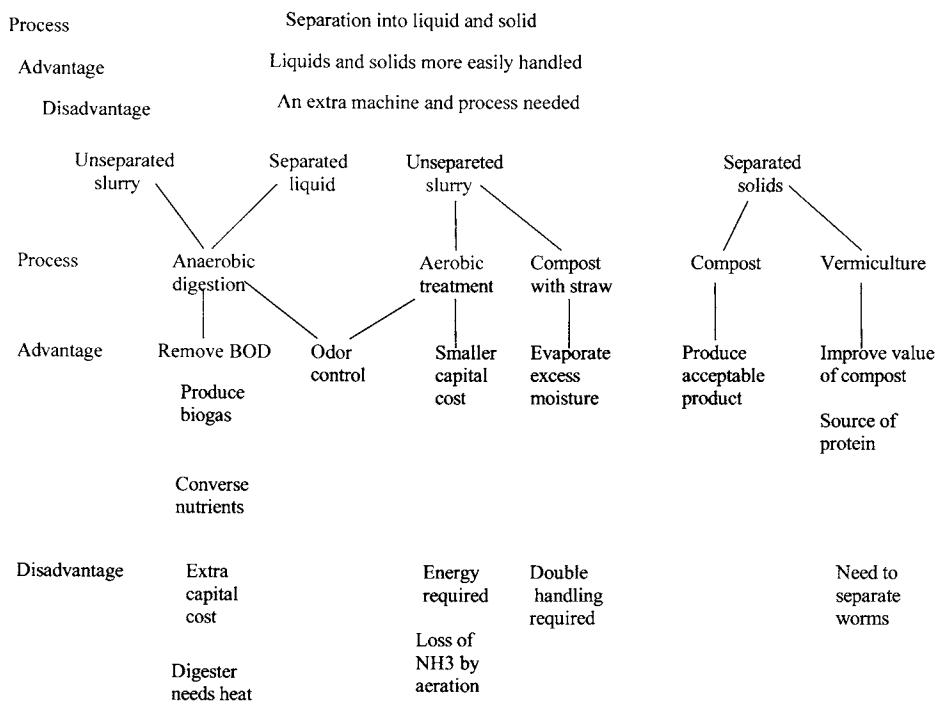


Figure VI.1.2. Treatment of slurry: advantages and disadvantages (after Gasser, 1984).

leaching of nitrate to ground waters (Gasser, 1984). Figures VI.1.3 and VI.1.4, respectively, show the distribution of  $\text{NH}_3$  and  $\text{NH}_4^+$  in Europe. Figure VI.1.5 shows the N-surplus per hectare in some EU countries and in Table VI.1.2 are given the estimated nitrogen losses from manure.

Table VI.1.1. Typical chemical composition (% dry matter) of faces for the main species of farm animals (after Smith, 1973).

Faces source	Neutral detergent soluble	Nitrogen	Hemi-cellulose	Cellulose	Lignin	Ash
% dry mater						
Broilers (caged)	69	6.5	16	11	4	22
Lying hens (caged)	65	6.2	17	15	3	28
Pigs (growing and fattening)	60	3.0	20	15	5	17
Beef cattle (fattening)	53	3.0	22	17	8	7
Dairy cattle (lactating)	41	2.6	21	25	13	9
Dairy cattle (all forage feed)	32	2.0	20	28	20	12
Sheep (all forage feed)	45	2.5	15	28	15	13

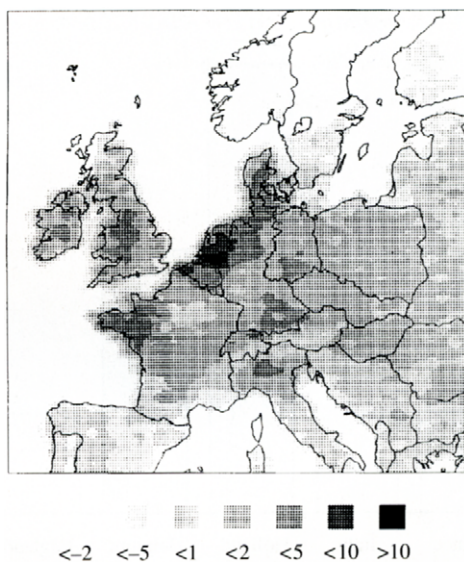


Figure VI.1.3. The calculated distribution of  $\text{NH}_3^-$  concentrations in air in Europe ( $\mu\text{g}/\text{m}^3$ ) (after Danish Energy Agency, 1993).

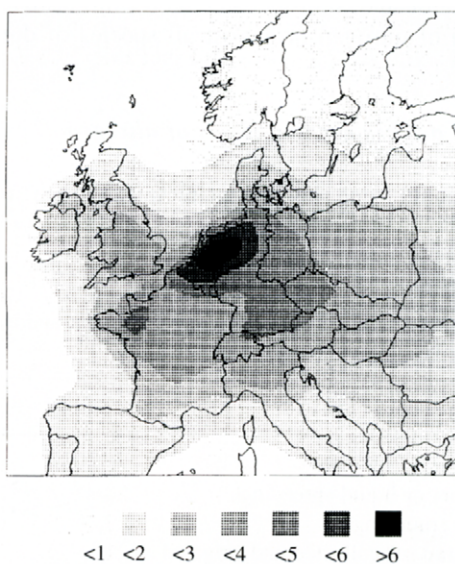


Figure VI.1.4. The calculated distribution of the  $\text{NH}_4^+$  concentration in air in Europe ( $\mu\text{g}/\text{m}^3$ ) (after Danish Energy Agency, 1993).

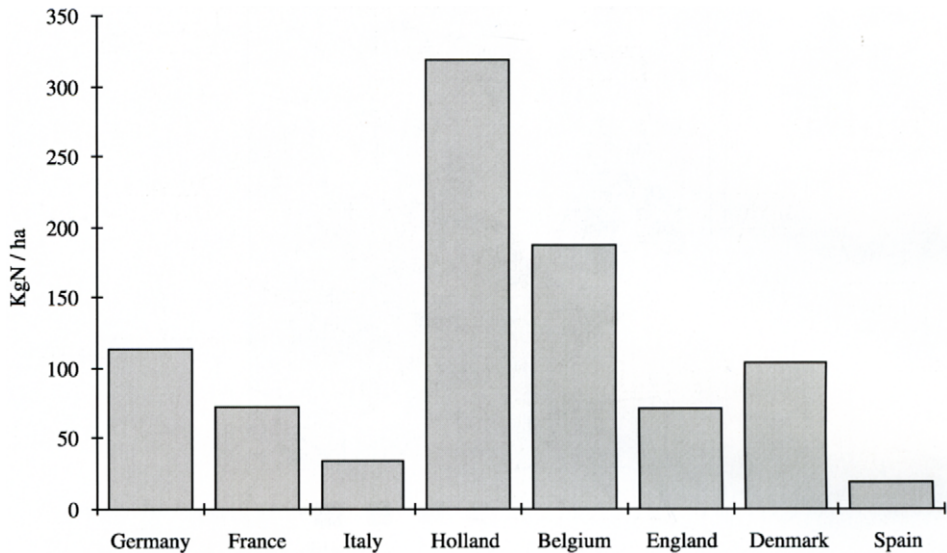


Figure VI.1.5. Nitrogen balance for eight EU countries (N-surplus, in kg/ha) (after Danish Ministry of Environment and Energy, 1994).

The variations in the amounts of nitrogen contained in manure can be large, depending on the digestibility of fodder and the content of proteins. Research work was carried out on the issue of controlling the amount of nitrogen contained in manure by optimized fodder composition. The research results concerning this issue have proven that improved systems of protein evaluation and controlled animal feeding with low protein content have improved the utilization of nitrogen in almost all species of domestic animals (Smith, 1973; Gasser, 1984).

#### VI.1.5.1. Nitrogen load per hectare and losses of nitrogen

Nitrogen from animal manure may be present in soil as three fractions (Landelout and Lambert, 1980):

Table VI.1.2. Estimated nitrogen losses during storage, treatment and handling of various manure management systems (after Bauder and Vogel, 1989–1990).

System	Nitrogen loss <sup>a</sup> (%)
Liquid pit or silo storage, liquid spreading	30–65
Anaerobic lagoon, irrigation, or liquid spreading	60–80
Bedded confinement, solid spreading	30–40
Open lot, solid spreading, run-off collected and irrigated	50–60

<sup>a</sup>Nitrogen loss values assume that manure is applied to the ground surface and is incorporated within few hours. If not incorporated, an additional loss of 30% on an average can be expected.

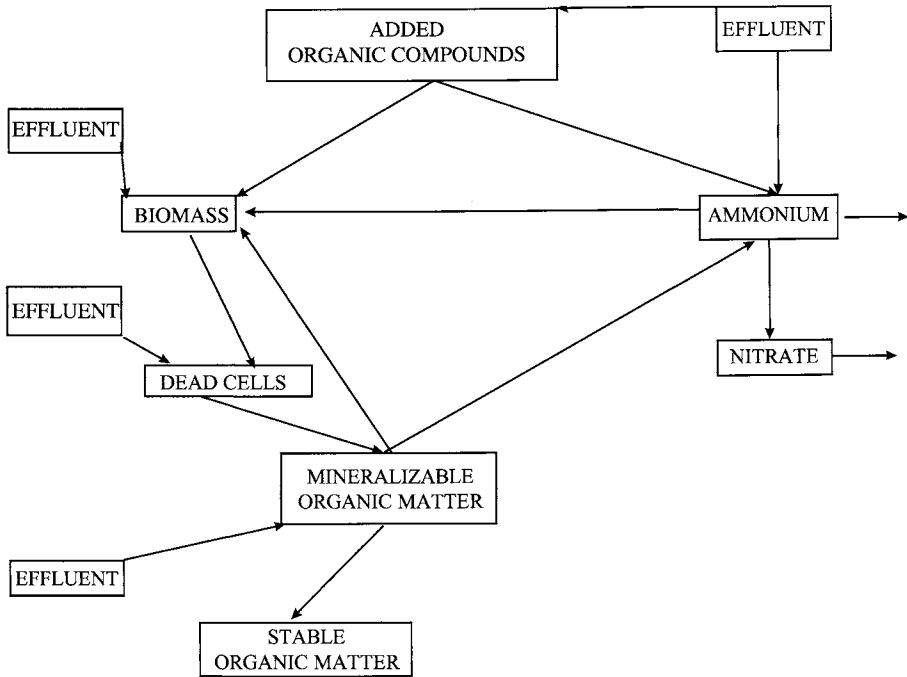


Figure VI.1.6. The simplified fluxes of N in the soil (after Landelout and Lambert, 1980).

- inorganic N (ammonium and some times nitrate) and rapidly mineralizable N from urea and uric acid;
- organic N compounds, easily degradable (with a low ratio of C/N) like proteins and amino acids;
- organic N slowly mineralizable (with high C/N ratio) like lignocellulose.

Manure also contains easily degradable N-free organic compounds like fats, fatty acids, carbohydrates, as well as organic and inorganic phosphorus compounds. Figure VI.1.6 presents a simplified scheme of nitrogen fluxes in the soil.

#### VI.1.5.1.1. Losses of nitrogen in the fields as ammonia

Animal manure is the main source of ammonia emissions to the atmosphere. The losses of ammonia are particularly large from heavily grazed grassland, surface-spread slurries and uncovered storage capacities. The losses of nitrogen as ammonia depend to a large extent on some factors such as pH, the content of dry matter, temperature, precipitation, wind, type of soil, the rate of covering with vegetation, etc.

The example of the influence of pH on ammonia loss from slurry is relevant. Ordinary slurry is alkaline (pH 7.0–8.0) and contains a large amount of N as  $\text{NH}_3$ , which is easily evaporable. Lowering the pH of the slurry by adding a strong acid will result in the presence of more N as  $\text{NH}_4^+$  that does not evaporate. Table VI.1.3 shows the variation of total ammonia content in slurry at different pH values.

Table VI.1.3. Variation of  $\text{NH}_3$  concentration in slurry according to pH values (after Danish Ministry of Environment and Energy, 1994).

pH value	6	7	8
% of $\text{NH}_3$ in $(\text{NH}_3 + \text{NH}_4^+)_{\text{total}}$	0.04	0.4	40

#### VI.1.5.1.2. Losses by denitrification

Losses of nitrate by denitrification results in the formation of  $\text{N}_2$  and  $\text{N}_2\text{O}$  and happens as a natural process in agricultural soils under reducing conditions, as a result of the activity of obligate anaerobic bacteria. Denitrification represents loss of a valuable nutrient for the plants, but in cases of excess manure, denitrification can be considered a beneficial removal of the excess nitrogen, avoiding groundwater pollution with nitrate. The process of denitrification can be prevented by ensuring adequate aeration in the soil, as denitrification occurs under reducing conditions.

#### VI.1.5.1.3. Losses by leaching of nitrate

Losses by nitrate leaching occur when excess nitrate is present, due to the application of excess slurry to the soil. It can be, e.g. when applying to grassland, when applying slurry during autumn and winter and with increasing intensity of grazed grassland (Landelout and Lambert, 1980). Improved nitrate efficiency can prevent this type of nitrate loss. Table VI.1.4 illustrates the increase in nitrate leaching with the increasing livestock density.

### VI.1.6. What controls the recycling of animal manure and organic wastes from food and agriculture

#### VI.1.6.1. The European framework

The increasing production of wastes of biological origin (biowaste) requires adequate collection, treatment and recovery methods. The general trend of both national and EU

Table VI.1.4. N-leaching related to density of LU/ha (after Danish Ministry of Environment and Energy, 1994).

Nitrogen source	Livestock units (LU/ha)	Average of N leaching (kg N/ha/year)
Crop production	0	68
Animal production	0–1	119
Animal production	1–2	160
Animal production	>2	170

legislation concerning management of agricultural wastes is to strengthen the environmental requirements and quality standards. Numerous EC regulations and guidelines have been issued in this area and more are about to be issued. The selection of regulations listed below (after Braun and Kirchmayr, 2003) have an impact on the practical applications of biological treatment of agricultural wastes, like anaerobic digestion and composting.

*VI.1.6.1.1. Council Directive 75/442/EEC of 15 July 1975 on waste*

The directive contains definition of wastes, guidelines for waste classification and exclusion of specific wastes (e.g. radioactive materials, animal carcasses, waste waters) as well as necessary measures to ensure safe waste disposal with respect to human health and environmental protection. EU member states are requested to take appropriate steps to encourage waste prevention, reuse and recycling, safe processing of waste, the extraction of raw materials and the energy recovery.

*VI.1.6.1.2. The Sewage Sludge Directive 1986/278/EEC*

The directive 1986/278/EEC "Protection of Environment and Soil at the Utilization of Sewage Sludge in Agriculture" defines the limit values for heavy metals, organic trace compounds and hygienic requirements for handling and application of sewage sludge on agricultural soils. In addition the Regulation on Organic Farming 2092/91/EEG defines heavy metal limit values for compost derived from source separate collection of municipal biowaste.

*VI.1.6.1.3. The Water Framework Directive 2000/60/EC*

The water framework directive affects water industry, agriculture, development and construction industry and all businesses that have discharge consents, trade effluent licenses or abstraction licenses. The aim of the directive is to establish a framework for the protection of waters and water environment by setting out a framework for action.

*VI.1.6.1.4. Council Directive 1999/31/EC on the Landfill of Waste*

The EC directive on the landfill of waste defines the goals of organic waste reduction in landfills, using as base of reference the year 1975. The input of organic waste to landfills should be reduced to 75% by 2006, 50% by 2009 and 35% by 2016.

*VI.1.6.1.5. Thematic strategy for soil protection*

A thematic strategy on soil protection will be presented by the EC in 2004. The strategy is one of the seven "thematic strategies" foreseen under the EU's 6th Environment Action Program. It will consist of legislation on community information and monitoring system on soil, as well as a set of detailed recommendations for future measures and actions. The monitoring system will build on existing information systems and databases and ensure a harmonized way of establishing the prevailing soil conditions across Europe. By the end of

2004 a directive on compost and other biowaste will be prepared with the aim to control potential soil contamination and encourage the use of certified compost.

*VI.1.6.1.6. Directive 2001/77/EC on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market*

The document states that the exploitation of renewable energy sources is underused in the community at the moment. For this reason the directive aims to promote an increase in the contribution of renewable energy sources to electricity production in the internal market for electricity and create a basis for a future community framework thereof. Biomass-based electricity and within it biogas is mentioned as one of the important renewable alternatives. To ensure increased penetration of electricity produced from renewable resources, the member states are requested to set appropriate national indicative targets.

*VI.1.6.1.7. Working document biological treatment of biowaste*

The second draft of the forthcoming regulation "Biological Treatment of Biowaste" was issued. The current version has to be harmonized with the recently published Animal By-product Regulation (EC) No 1774/2002 and a revised third version is expected in 2004. The forthcoming regulation will contain lists of allowable wastes for biotreatment, directives for waste collection, handling and treatment, approval criteria for treatment plants and allowable processing emissions, quality classes for biotreatment of residues and compost, control and analysis of end-products and their application standards. As an example, sanitation of biowaste has to be done at a minimum temperature of 55°C for at least 24 h, at an average hydraulic dwell time in the reactor of at least 20 days. If that is not guaranteed, then a pre-treatment at 70°C for 1 h or a post-treatment of the solid digestate at 70°C for 1 h or composting of the solid digestate is required.

*VI.1.6.1.8. Animal By-products Regulation (EC) No 1774/2002*

The Regulation (EC) No 1774/2002 of the European Parliament and the Council from October 2002, laying down health rules concerning animal by-products not intended for human consumption, was enforced in all EU member states by 01.05.2003 as a comprehensive attempt to ensure food safety and animal and human health. The regulation is undergoing an amendment process and transitional measures were proposed in several member states.

It is estimated that more than 14.3 million tons (1998) of animal by-products derived from healthy animals, not intended for human consumption, are processed in EU countries every year. These materials are further transformed into a variety of products used in human food, animal feeding, cosmetics, pharmaceuticals, etc. In 1998 16.1 million tons of animal by-products (of which 14.1 million tons derived from healthy animals) were processed into 3 million tons of meat and bone meal and 1.5 million tons of fat (COM(2000)574).

Inappropriate processing standards and the use of rendered products and catering waste are considered to be the reason for major pandemic outbreaks of transmissible spongiform encephalopathy and foot and mouth disease. The regulation brings major changes in

processing procedures by both waste producers and waste managers. Animal by-products are defined as all animals or parts of animals not intended for human consumption. This also includes dead-on-farm animals, animal manure and catering waste. The animal by-products are classified into three categories of risk and new rules for their collection, treatment and disposal are introduced.

#### ***VI.1.6.2. National regulations – case study from Denmark***

A series of continuously amended and strengthened regulations and legislation concerning production, collection, storage, handling and recycling of animal manure and organic wastes have been introduced in Denmark since 1985, as a result of some serious environmental problems related to intensive animal production and increased production of organic waste from the food processing sector and from the overall society.

Long-term governmental programs and plans for optimal recycling of animal manure and other organic wastes have been implemented in Denmark. The Danish environmental legislation prescribes integrated recycling of suitable organic waste in the farming system and enforces restrictions to secure a safe recycling policy, and to prevent hazards for human and animal health and further pollution and contamination of the environment.

Cleaner technologies, with integrated recycling practices, were developed throughout the years, as well as biomass-based energy systems, due to their feasibility of simultaneously renewable energy, diminishing environmental pollution and obtaining agricultural benefits. The Danish Ministry of Environment and Energy (1992, 1994, 1996, 1999, 2000) introduced and repeatedly strengthened the regulations concerning the handling and application of animal manure, sewage sludge and compost. Some of the statutory orders regulating this area will be further reviewed. The Danish Veterinary Service, under the Ministry of Agriculture and Fisheries, sets standards and runs monitoring programs for sanitary safe utilization of waste products for agricultural purposes (1996).

The agricultural sector has influenced the legislative process. This has directed the regulations towards use of clean technology, elimination of point sources, larger storage capacities, better spreading techniques, change in crop rotation, green fields in winter time, more areas with permanent grassland, etc. The agricultural sector used different policy instruments such as information campaigns like “slurry is gold” aiming to improve the utilization of nitrogen in manure, establishment of more than 600 pesticide groups that seems to contribute to reduction of pesticides up to 25% (1996) compared with the previous national average.

The agriculture sector refused “the polluter pays” principle, and the farmers have received support to build slurry tanks instead and accepted clear political goals of reduction of total nitrogen leaching from the field and reduction of pesticides load per hectare. The national schemes reward farmers producing in an environmentally friendly way. The Danish agro-environmental policy segment has developed (see Table VI.1.5) and is clearly more environmentally integrated and less politically influenced than in the 1980s, with more clearly defined actors and problem issues (Just, 1994).

Table VI.1.5. The Danish agro-environmental policy segment (after Just, 1994).

Time period	Driving forces	Environmental priorities	Most important administrative actor
1960s	State	Open nature conservation	State
1970s	Social movements	Antipollution	Ministry of Environment
1980s	Green movements, scientists, politicians	Agriculture as a polluting activity	Ministry of Environment, Municipalities
1990s	Agro-environmental segment	Integrated environmental protection	Ministry of Environment, Ministry of Agriculture, Municipalities, Counties

#### VI.1.6.2.1. Manure regulations in Denmark

Since 1985 legislation has regulated Danish agriculture in order to protect the ground- and surface water environment. New law packages were adopted several times during the last decade, and the existing ones were continuously amended and strengthened.

- *Requirement of 6–9 months slurry storage capacity, restricting the seasons for slurry application* (statutory order from the Ministry of the Environment No 1121 of 15/12/1992, on professional livestock, livestock manure, silage, etc.).

According to the law, holdings with commercial livestock keeping and holdings, which store farmyard manure, must have sufficient storage capacity to observe the rules concerning spreading of farmyard manure and utilization of nitrogen from farmyard manure. At least 6 months' storage capacity is required. Sufficient storage capacity corresponds to at least 9 months' supplies, for cattle farms normally at least 7 months when the cattle are pasturing during summer. Consequently, the season for liquid manure application is restricted and the application is not allowed from harvest to February 1st, except for the period from harvest to October 1st in over-wintering grassland crops or on areas with winter rape the following winter. Liquid manure is to be immediately incorporated in soil or no more than 12 h after application.

- *The harmony rules, restricting the amount of manure applied per hectare* (statutory order from the Ministry of the Environment No 906, of 14/10/1996, on professional livestock, livestock manure, silage, etc.).

The harmony rules regulate the maximum input of nitrogen per hectare per year by prescribing the maximum allowed livestock units (LU) loading per hectare and were enforced in 1987 by the Water Environment Action Plan I. The statutory order defines a livestock unit as "a unit of calculation" corresponding to "a maximum of 100 kg of nitrogen in manure, including the quantity deposited by the animals on the field." The prescriptions of the harmony rules are outlined in Table VI.1.6.

- *Minimum coefficients of nitrogen efficiency from animal manure* (statutory order No 587 from 12/07/1999 on utilization of manure as agricultural fertilizer).

The first action plan for sustainable agriculture in 1991 sets up minimum coefficients for the utilization of nutrients from animal manure, in force from the crop year 1994. In 1998, the Water Environment Plan 2 further increased the utilization requirements and

Table VI.1.6. Maximum amounts of nitrogen from manure to be spread per ha per year (converted to kg total N/ha/year) (after Birkmose, 1999).

Type of farm	Until 12/2003	From 12/2003
Cattle farm 1, <70% grass and beets	210	170
Cattle farm 2, >70% grass and beets <sup>a</sup>	230	230
Pig farm	140–170 <sup>b</sup>	140
Other animals or mixed	Approx. 200 <sup>c</sup>	140
Farms without livestock	140–170 <sup>b</sup>	140

<sup>a</sup>The derogation of the EU nitrate directive allows spreading more than 170 kg manure per ha, if larger area is covered with crops with high autumn N intake.

<sup>b</sup>1.7 livestock units per ha – the amount of nitrogen may vary, depending on the relation between sows and pigs for slaughter.

<sup>c</sup>2.0 livestock units per ha.

the coefficients were to be raised in the years to come. In case of pig slurry, for example, the minimum nitrogen utilization coefficient (first year utilization + second year) was 50 + 10% in 1998–1999, 55 + 10% in 1999–2000 and 60 + 10% in 2001–2002. To control the fertilizer use, the farmers must work out compulsory annual fertilizer plans, and submit annual fertilizer accounts to the Danish Plant Directorate. The positive effects of this legal requirement are reflected by the decreasing input of mineral fertilizers. Figure VI.1.7 shows the clear trend of decreasing overall mineral fertilizers' consumption in Denmark, as a consequence of increasing manure nutrient utilization.

#### VI.1.6.2.2. Organic waste regulation

The Danish waste legislation is characterized by a close interplay between EU regulations, regarding the overall frameworks and principles, and the national waste model, based on a combination of traditional administrative instruments (acts, statutory orders, etc.) and various other instruments such as taxes, charges, subsidies, agreements, etc. The legal framework for waste management in Denmark is given in the Danish Environmental Protection Act (1997) and the subsequent statutory orders and circulars, of which the most important is statutory order on waste No 299 of 30/04/1997 that corresponds with EU Council Directive 75/442/EEC (1975) on waste amended by Council Directive 91/156/EEC (1991) and with the waste management strategy defined and pursued by the European Union (EC DG ENV, 1999). The Danish Government Action plan for waste and recycling emphasizes the importance and the incentives and rules for recycling the plant nutrients between the urban and rural areas.

- *The application of waste products for agricultural purposes is controlled and regulated* (statutory order from the Ministry of Environment and Energy No 49 of 20/01/2000, on application of waste products for agricultural purposes).

Organic wastes can contain organic contaminants, heavy metals and pathogens, which can accumulate in the soils, or create chains of disease transmission between animals, humans and the environment (see Chapter III.1). The legislation outlines the types of organic wastes that can be applied on agricultural soil without restrictions and the types

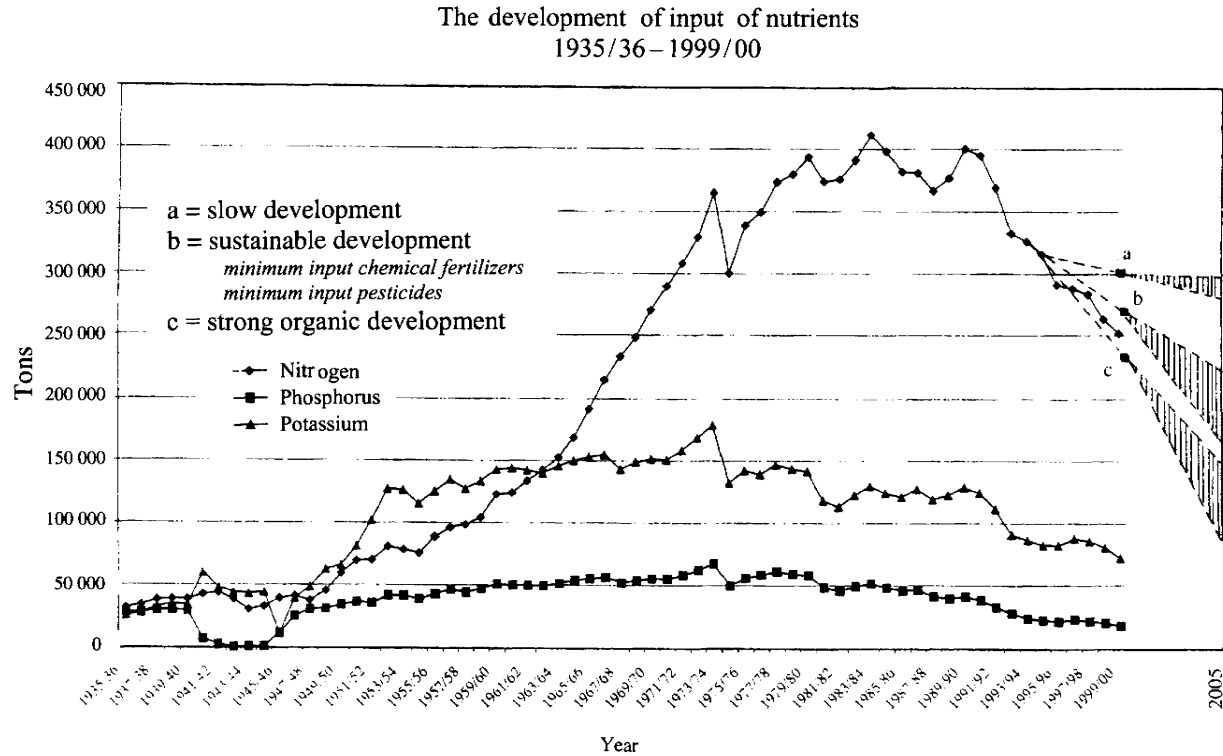


Figure VI.1.7. The evolution of the total consumption of artificial fertilizers in Denmark in the period 1935/1936–1999/2000 (after Danish Ministry of Agriculture and Fisheries, 2001) (a, b and c scenarios by Holm-Nielsen and Al Seadi (2001)).

Table VI.1.7. Controlled sanitation equivalent to 70°C for 1 h, as required by the Statutory Order 49 (after Danish Ministry of Environment and Energy, 2000).

Temperature (°C)	Retention time (MGRT) in a thermophilic digester <sup>a</sup> (h)	MGRT <sup>b</sup> by treatment in a separate tank	
		Before/after thermophilic digestion (h)	Before/after mesophilic digestion <sup>c</sup> (h)
52.0	10	–	–
53.5	8	–	–
55.0	6	5.5	7.5
60.0	–	2.5	3.5
65.0	–	1.0	1.5

<sup>a</sup>Thermophilic digestion is here defined as minimum 52°C, for at least 7 days hydraulic retention time (HRT).

<sup>b</sup>Minimum guaranteed retention time (h).

<sup>c</sup>Mesophilic digestion is here defined as 20–52°C, for at least 14 days hydraulic retention time (HRT).

that require previous treatment, setting up quality standards for the waste products utilized for agricultural purposes. Table VI.1.7 shows an example of requirement of controlled sanitation, for the anaerobic digestion of sewage sludge and other types of organic waste, in order to allow the use of digestate as fertilizer in agriculture.

### VI.1.7. Environmental benefits, renewable energy and natural fertilizer from co-digestion of animal manure and organic wastes in Denmark

The agro-environmental legislation outlined earlier motivates the farmers to supply their animal manure and slurries to a centralized biogas plant in order to meet the legal requirements. The Danish livestock counts approximately 2.4 million livestock units, producing approximately 48 million tons of manure per year, of which approximately 1 million tons are supplied to the biogas plants. In Denmark, 20 manure-based centralized co-digestion plants are in operation, processing approximately 1 million tons animal manure and 325,000 tons alternative biomass per year, and producing 50.1 million m<sup>3</sup> biogas (1999 data).

#### VI.1.7.1. The Co-digestion concept

The first generation of centralized co-digestion plants in Denmark was built in the early 1980s with the only aim of producing renewable energy. The co-digestion concept was continuously developed and improved and represents today an integrated system of renewable energy production, manure and organic waste treatment and nutrient recycling (Fig. VI.1.8), generating intertwined agricultural and environmental benefits (Jepsen, 2002):

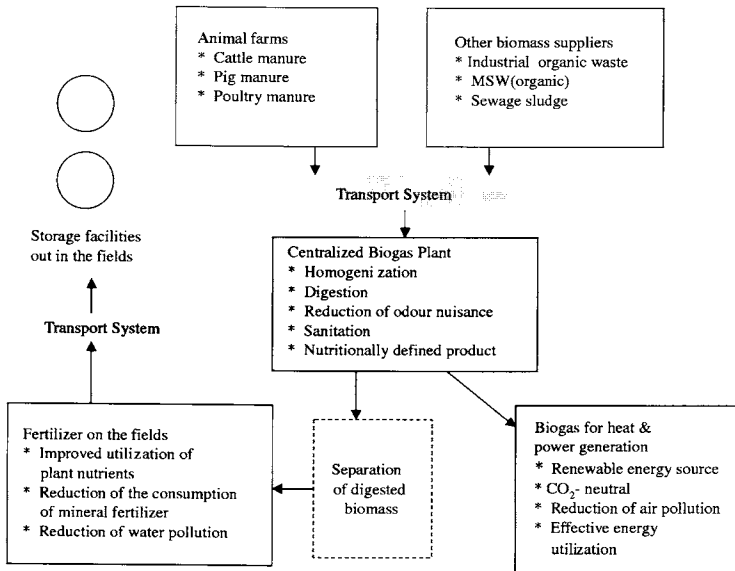


Figure VI.1.8. The main streams of the integrated concept of centralized co-digestion plant (after Hjort-Gregersen, 1999).

- renewable energy production;
- cheap and environmentally sound organic waste recycling;
- less greenhouse gas emission;
- pathogen reduction through sanitation;
- improved fertilization efficiency;
- less nuisance from odors and flies;
- economical advantages for the farmers.

According to the above-described concept, animal manure and slurry are collected from the farmers' pre-storage tanks, transported to the biogas plant, mixed and co-digested with maximum 15–25% digestible organic wastes (also called alternative biomass) from agriculture, food processing industries and municipalities, and submitted to a controlled sanitation process, ensuring effective pathogen reduction.

The digestion process takes place at mesophilic (30–40°C) or thermophilic temperatures (50–55°C), during 12–25 days. A controlled sanitation process takes place as well, where pathogens are effectively reduced, and the contamination cycles are broken. The digested biomass is transferred to the storage tanks, covered with a gas-proof membrane for the recovery of the remaining biogas production (up to 15% of total). Some plants are equipped with installations for fiber separation of the digested biomass, but these technologies are still under development.

The digested biomass is transported back to the farmers, at their storage tanks, placed out in the fields, as a pathogen-free, nutritionally defined fertilizer, to be integrated in the fertilization plan of each farm. The biogas produced is used for combined heat and power generation. The power is sold to the grid and the heat is distributed through the district-heating network to heat consumers. Some of it is used by the biogas plant for process heating.

The legal requirement of 6–9 months slurry storage capacity means a considerable investment for the Danish farmers. The centralized co-digestion plants have built slurry storage capacities for the associated farmers, providing important cost savings from manure storage (Danish Energy Agency, 1995a,b; Holm-Nielsen et al., 1997; Hjort-Gregersen, 1999; Al Seadi, 2000; Al Seadi et al., 2001). Up to 40% investment government grants were given for the establishment of 9 month storage capacity if the farmer supplies the slurry to a biogas plant. The location of the storage tanks is chosen close to the fields where digestate is to be applied and the biogas plant effectuates and supports the cost of biomass transport, providing the slurry suppliers with important cost savings from manure transport.

Danish experience shows that the nitrogen efficiency from digestate application is higher than that from untreated slurry, if the good agricultural practice for digestate application is respected (Holm-Nielsen et al., 1997; Danish Ministry of Agriculture and Fisheries, 1996, 1997). The slurry suppliers also obtain economical benefits in the form of cost savings from chemical fertilizer purchase. The farmers supplying slurry to a centralized biogas plant are also helped to meet the harmony requirements, as they receive back only that amount of digestate they are allowed to spread according to the law. One of the main environmental functions of a centralized plant is the redistribution of manure, and the common practice is that the excess digestate is transferred to arable farms in the area, and the centralized plant supports the cost of transport. The possibility of co-digesting up to 25% alternative biomass offers, to the farmers, opportunities for extra income from the gate fees and from enhanced biogas production. It is also considered a sustainable way of treatment and recycling of the suitable organic wastes.

#### ***VI.1.7.2. The place of biogas in the Danish energy strategy***

The acknowledgement of the environmental consequences of the intensive animal production, the strengthening of the legislation regarding manure storage as an application, regulations of waste production and treatment increased the interest for biogas plants, which proved to play a new role as providers of manure storage, manure distributors and organic waste treatment facilities. In recognition of this, the Danish Government financed successive RD&D programs and follow-up programs, which proved that the concept offers integrated solutions to a range of environmental problems related to agriculture, waste treatment and energy production. The biogas sector has therefore received growing attention and recognition in Denmark during the last decade. Denmark has an obligation of reducing the emissions of greenhouse gases (CO<sub>2</sub>, methane, N<sub>2</sub>O and other industry gases) by 21% until year 2012, compared to 1990 as reference year. Biogas shall provide 20 PJ to the national energy production, by year 2030, an 8-fold increase compared with the 1998 level and by this the greatest growth compared with other renewables. In 1999, 2.67 PJ was produced in Denmark from biogas. A significant part of it originates from the large-scale, manure-based co-digestion plants (Table VI.1.8).

The theoretical biogas potential in Denmark is estimated at 34 PJ of which 24 PJ (70%) is represented by animal manure. Energy 21 forecasts 20 PJ by 2030 (Table VI.1.9) that shall mainly emerge from manure-based biogas plants.

Table VI.1.8. Biogas plants and production in Denmark, 1999 (after Danish Energy Agency, 2000).

Type of biogas plant	Amount of plants	Production (PJ)
Wastewater treatment plants	64	0.680
Landfill plants	17	0.550
Industrial waste treatment plants	5	0.150
<i>Manure-based plants</i>		
Centralised, co-digestion	20	1.240
Farm scale plants	25	0.050
Total	132	2.670

### VI.1.8. Conclusion

The farming communities represent the main sector and the driving force for a green movement in the rural communities of Europe. The incentives are various: increasing the sustainability of the farm, new income source from selling green electricity to the grid, solving the environmental problems of emissions and odors from manure, better utilizations of farm resources, etc. Further improvement of the utilization of agricultural wastes for industry and renewable energy purposes and for overcoming the existing technical and non-technical barriers must be based on the environmental and economical benefits derived from it and could be directed as:

- Programs to stimulate utilization and recycling of agricultural waste/organic resources;
- Harmonization of animal manure storage, handling and application requirements throughout the EU. Focus on environmental problems of industrialized animal production, such as large-scale production, with no or little land area to recycle manure and organic wastes through crop production.

Table VI.1.9. Potential, actual production and targets for biogas in Denmark (after Danish Energy Agency, 2000).

Energy source	Potential (PJ)	Production 1999 (PJ)	Target prod. 2112 (PJ)	Target prod. 2030 (PJ)
Animal manure	24.0	0.50	3.00	13.0
Sewage sludge	3.0	0.79	1.15	1.5
Organic waste from industries	2.0	0.81	1.50	2.0
Household waste (organic)	2.5	0.01	0.70	2.2
Green waste (parks and gardens)	1.5	0.00	0.25	1.2
Landfill gas	1.0	0.55	0.40	0.1
Total	34.0	2.67	7.00	20.0

- An overall strategy of mandatory harmony between animal stocking rate and farmland area, or demands for maximum limits of nitrogen and phosphate fertilization, following EU environmental strategies, exemplified in the nitrate directive (EEC, 1991).
- Improvement of the present biomass for industry and energy technologies:
  - reduced costs of advanced technologies,
  - developing suitable scale systems,
  - RD&D programs.
- Programs for active promotion and dissemination of well-established technologies and knowledge transfer.
- An overall policy to stimulate fuel and electricity production from renewable sources

The utilization of agricultural wastes for industry and energy purposes will depend to a large extent on availability. Availability and implementation is dependent on agricultural, environmental and energy policies (Nordberg, 1999). The growing awareness of the pollution problems, associated with inadequate management of animal manure and organic wastes, emphasizes the need for appropriate solutions to deal with the problem. A strengthening of the overall policy on environmental protection in relation to the organic agricultural wastes as well as the animal manure handling and utilization, with well-defined enforcement measures, will stimulate the implementation of the appropriate utilization and recycling strategies.

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