Diffusion of a sustainable EU model to produce 1st generation ethanol from sweet sorghum in decentralised plants

Intersectorial Manual
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The bioethanol produced from sweet sorghum is sustainable in terms of environmental remarks and economic viability: the attributed GHGs emissions saving meets the European target to 2018 (i.e. about 60%) and the exploitation of by-products guarantees the economic viability also for decentralised small-medium plants (i.e. 10,000 t/y).

In the current situation the EU bioethanol market is controlled by big industrial groups and large agricultural cooperatives of the sugar and alcohol industries and mainly cereals are processed in big plants (100,000-200,000 t/y). This situation is due to some relevant barriers: economic, logistical, ecological, environmental, social and dissemination barriers.

The SWEETHANOL project, supported by the Intelligent Energy program of the European Commission, is aimed to change the current situation concerning the raw material diversification, decentralisation and development of energy chain using sweet sorghum, which can be grown in the southern regions of the EU.

The absence of know-how about the potentialities of sweet sorghum as energy crop, to produce sustainable bioethanol and other energy commodities in decentralised plants, has been overcome through an widespread discussion of the main technical and non-technical aspects with the market players. This pathway will be completed with the training of the stakeholders.

This intersectorial manual follows the “Sweethanol – Technical manual” and “Sweethanol – Administrative manual” and it is specifically aimed to integrate the data about the production chain with the information about the scenario for its development in the EU.

Consequently the “Sweethanol – Intersectorial manual” is the final output of the project and it is one of the main tools to definitively overcome the non technical barrier for the diffusion of sweet sorghum as bioethanol and energy crop suitable to the conditions of the South EU.

Specifically its contents are the basis to implement feasibility studies and to start up new entrepreneurship in the bioenergy sector using sweet sorghum.

In order to simplify this utilisation, the manual has been planned to highlight some general guidelines to use sweet sorghum as energy crop and to explain two chain models to supply a decentralised plant with some case studies, contextualised in the different countries participants in the project (i.e. Italy, Greece, Spain).

This “Sweethanol – Intersectorial manual” is the didactic tool for the training of the stakeholders in the courses, which will be carried out in all the consortium countries.

In order to emphasise the transferability of the EU model in the not-participant countries, where sweet sorghum can be grown, a specific chapter has been planned to assess the national scenarios for the diffusion of the EU model in Romania, Bulgaria, France, Portugal, Croatia and Hungary.

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3. **LIST OF ACRONYMS AND ABBREVIATIONS**

ABI agri business incubator (India)
AEBIOM European association of biomass
ASP agri science park (India)
B10 biodiesel 10% v/v blend
B30 biodiesel 30% v/v blend
Bio-ETBE ethyl-ter-butyl-ether obtained from bioethanol
Bio-SPK bio-derived synthetic paraffinic kerosene
BOD biochemical oxygen demand
CAP common agricultural policy
CAICYT advisory committee on scientific and technical research (Spain)
CCHP combined cool, heat and power production
CH\(_4\) methane
CHP combined heat and power production
CO carbon monoxide
CO\(_2\) carbon dioxide
COD chemical oxygen demand
CRA-CIN council for the research and experimentation in agriculture – research centre for the industrial crops (Italy)
CRA-ING council for the research and experimentation in agriculture – research unit for the agricultural engineering (Italy)
CRA-RPS council for the research and experimentation in agriculture – research centre for the study of the relationship between plant and soil (Italy)
CRES centre for renewable energy sources (Greece)
Crpa S.p.A. centre research animal production (Italy)
db dry basis
DCU decentralised crushing unit (India)
DDG distillers dried grains
DDGS distillers dried grains with solubles
DPI integrated production specifications
E10 bioethanol 10% v/v blend
E15 bioethanol 15% v/v blend
E85 bioethanol 85% v/v blend
E90 bioethanol 90% v/v blend
E100 bioethanol 100 %
EC European commission
ENEA national agency for the new technologies, energy and sustainable economic development (Italy)
ETEAN national fund for entrepreneurship and development (Greece)
EU European Union
FAME fatty acid methyl ester
FIT feed in tariff
FFV flexible fuel vehicles
FP framework program of the EC
FYROM Former Yugoslav Republic of Macedonia
GDP gross domestic products
GHGs green house gases
GSE provider of the electrical services (Italy)
H$_2$S sulphidric acid
HHST higher heat shorter time
HRT hydraulic retention time
HTST high temperature short time
HVO hydro-treated vegetable oils
ICRISAT international crop research institute for the semi-arid tropics (India)
IEE intelligent energy europe program
ILUC indirect land use change
IMA industria meridionale alcolici (Italy)
INIA research and technology national agriculture and food (Spain)
IPPC integrated pollution prevention and control
IRR internal rate of return
JMD joint ministerial decision (Greece)
K$_2$O potassium oxide
KEOP environmental and energy operational program (Hungary)
LCA life cycle assessment
LCFS low carbon fuel standard (US, California)
LHV low heating value
LPG liquefied petroleum gas
LUC land use change
MATTM ministry of the environment, protection of the territory and sea (Italy)
MIPAAF ministry of agriculture and forestry (Italy)
MON motor octane number
MSE ministry for economic development (Italy)
MSW municipal solid wastes
MTBE methyl-ter-butyl-ether
N$_2$ molecular nitrogen
N$_2$O nitrogen oxide
NAP national action plan (Italy)
NEC national energy commission (Spain)
NO\textsubscript{x} nitrogen oxides
NREAP national renewable energy action plan (Greece, Spain)
O\textsubscript{2} molecular oxygen
ORC organic Rankine cycle
O&M operative and maintenance
P\textsubscript{2}O\textsubscript{5} phosphorus pentoxide
PM particulate air pollution
R.A.E. regulatory authority for energy (Greece)
RD royal decree (Spain)
R&D research and development
RED renewable energy directive, 2009/28/EC
REP renewable energy plan
RES renewable energy sources
RFS renewable fuel standards (US)
RFS2 renewable fuel standards 2 (US)
rpm revolutions per minute
RON research octane number
RUE radiation use efficiency
SMEs small medium enterprises
SO\textsubscript{2} sulphurous anhydride
toe tons of oil equivalent
TRPF toothed roller pressure feeder
UP ultra pasteurisation
US United States of America
VOC volatile organic compounds
v/v volume/volume
wb wet basis
w/w weight/weight
WUE water use efficiency
ZVAIEB renewable and alternative energy sources on biofuels act (Bulgaria)
4. SWEETHANOL PROJECT

SWEETHANOL is a project financed and supported by the EC in the ambit of the program IEE-II 2009 (Intelligent Energy Europe), action “ALTENER” – New and Renewable Energies sources.

It is a project related to the diffusion of a sustainable EU model to produce bioethanol and other energy commodities from sweet sorghum in decentralised plants. The project is organised in the following actions:

- know-how refining about the bioethanol production from sweet sorghum. The more interesting data (e.g. investment costs, energy consumption, production costs, bioethanol yield, by-products exploitation) are collected visiting the agricultural research institutes, the plant construction companies and the existing plants;

- sustainable model discussion of the EU model with representatives of each chain player. The chain players (i.e. farmers, agricultural associations, fuel processors, SMEs, seeds and agricultural companies, investors, policy makers and public authorities representatives, energy agencies) are engaged in an EU model discussion through sectorial and intersectorial workshops at national and international level;

- chain actors training through tailor-made courses per categories of chain actor;

- creation and management of the online community (i.e. “Esse community”, link: http://esse-community.eu/), a virtual place where all the chain actors may create the network in order to share and gather information about the sweet sorghum bioethanol chain: articles, info about events, blog, forum, social network, teleconferences and reputation management are performed.

The project covers the following priority activities:

- encouraging market players in the bioethanol supply chain to increase the economic competitiveness and environmental sustainability of the biofuel itself;

- supporting and promoting the application of sustainability criteria for bioethanol;

- addressing the issues under discussion in the current debates on land use and sustainability;

- facilitating and promoting the well-informed debate and the balanced attitude among decision makers and the general public.

The main objectives of the project are:

- know-how diffusion about the sustainable EU model

The sustainable EU model is shared among the chain actors which accept it through the discussion of the technical, logistic, economic, financial, energetic, environmental and administrative aspects and it will be widely spread by each target group. Consequently, as market players, they are encouraged to start up new entrepreneurship to increase the economic competitiveness and at the same time the environmental sustainability of bioethanol. The changes in the bioethanol market are the enhanced raw material diversification, decentralisation of the production and sustainability of bioethanol (mainly as GHGs saving). The proposed wide discussion about the production of bioethanol using sweet sorghum contributes to
address the current debates on land use and sustainability and to facilitate and promote a well-informed discussion and a balanced attitude amongst decision makers and the general public.

- daily updating through the network building and the supply chain co-ordination

Through the “Esse Community” the market players are able to count on daily updating of the legislative, administrative and technical aspects related to the bioethanol production and market (in general, and specifically using sweet sorghum). The daily offered updated service simplifies the market analysis necessary for the start up of new entrepreneurship; consequently the diversification of the bioethanol market is stimulated and the market centralisation among few numbers of chain actors is contrasted. Moreover, the network building contributes to address the issues under discussion in the current debates on land use and sustainability and to facilitate and promote a well-informed debate and a balanced attitude amongst decision makers and the general public.
5. SWEETHANOL PARTNERSHIP

CETA – Centre for theoretical and applied ecology - Italy
CETA was created in 1987 in Gorizia (Italy) and is a non-profit association which carries out research, applied experimentation and innovative technology development in four areas: environment such as sustainable management of environmental and natural resources (water, soil, landscape) and environmental balances and models of environmental accounting; energy such as promotion and diffusion of renewable energy technologies (biomass, biogas, biofuels, solar energy – photovoltaic, geothermal, hydroelectric), energy efficiency, energy planning, analysis and models of territory management, costs-benefits and multi-criteria analyses; territory such as strategic planning and programming, Government of the territory (large area and local level), studies of environmental impacts and strategic environmental evaluation, and knowledge such as experimentation of production and innovation models for fuel biomasses and biofuels of 2nd and 3rd generation, research and development of energy crops with low environmental impact for energy production. CETA carries out its own multidisciplinary activities employing high-degree professionals such as engineers, agronomists, biologists, naturalists, economists, architects.

Foundation CARTIF – Technological centre - Spain
CARTIF was created in 1994 as the Automation, Robotics, Information and Manufacturing Technology Centre, a non-profit association focused on applied research and based in Boecillo Technology Park, Valladolid (Spain). From October 2005, CARTIF is legally established as a Foundation keeping its main goals: identifying technology needs and developing R&D-based knowledge, supporting technological innovation in Industry mainly among SMEs and disseminating R&D and innovation results.

REACM– Regional energy agency of Central Macedonia – Anatoliki S.A. - Greece
Region of Central Macedonia and Local Development Agency of Eastern Thessaloniki’s Local Authorities- Anatoliki S.A. established REACM in 1997, through the European Union’s SAVE programme. The main activities include: data acquisition for energy production and consumption in the region, support to the region’s local authorities in energy policy planning and sustainable energy actions planning, dissemination activities for RES and RUE technologies, training and education, mobility management on municipal level, promotion of biofuels, support to local industry, SMEs & commercial, pilot application of EMAS in heavy industries in Thessaloniki, training of personnel in industrial sector in ECO-Energy audits, promotion of RES technologies to the agricultural sector, definition of REP, collaboration with neighbouring countries in energy savings, participation in regional planning for development and management of geothermal fields.

INIPA- Coldiretti - Italy
INIPA is the research, training and development National Department for agri-food, environmental and services sectors of Coldiretti (The National Confederation of
Farmers - Italy), and it is a legally recognized non-profit organization. It is a unitary structure distributed throughout the country, with associated institutes at regional level and territorial divisions. INIPA promotes, organizes and participates (in partnership with leading agencies at both National and European Community level) in research, scientific information and training for farmers, organizations and territories pointing out the results in favour of the continuous innovation of the agri-food system.

**ADABE – Association for the diffusion of biomass - Spain**
ADABE is a national association, no-profit, founded in 1986 according to the Directorate General of Domestic Policy of the Ministry of Interior. It is a founding member of AEBIOM based in Brussels, founded in 1990. It brings together individuals and entities involved in research, technology and/or dissemination of the use of biomass in Spain.

**Agricultural co-operative of Halastra - Greece**
The major activities of the agricultural co-operative of Halastra include: services related to agricultural products (e.g. rice, corn, cotton, wheat, cereals), collection, drying and storage of agricultural products, sale of agricultural supplies, sale of agricultural products on behalf of the members of the association, retail of agricultural goods, rice packaging and trade.
6. BIOETHANOL – A STRATEGIC BIOFUEL FOR THE EU

6.1 Characteristics

Bioethanol is ethyl alcohol that derives from the alcoholic fermentation of sugars or hydrolysed polysaccharides (e.g. starch, cellulose). In this process glucose, along with water, is converted into ethanol, CO₂ and water. The chemical reaction of sugar into ethanol is described as follows:

\[ C_6H_{12}O_6 + H_2O \rightarrow 2C_2H_5OH + 2CO_2 + H_2O \]

Bioethanol use as a fuel is realised by the exothermic reaction when burnt, producing CO₂ and water. The chemical reaction of ethanol burning is the following:

\[ C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O \]

Generally the term bioethanol is applied specifically for ethanol used as a component in transportation fuel.

Bioethanol can be classified as biofuel of first, second or third generation depending on the used raw materials for its production, but the final characteristics of the product are the same.

Bioethanol for its chemical and physical properties can substitute the petrol in the Otto cycle engines. It is plausible that after the engine experimentations also in the Diesel engines bioethanol could be used. The chemical and physical properties of bioethanol are reported in Table 1.

For some properties bioethanol has a better behaviour than petrol because of its higher antiknock capacity due to the higher value of the octane number. The volatility of bioethanol, expressed by the boiling temperature and the vapour pressure is higher than the petrol one. The consequence is faster and homogeneous mixing with air during the carburation that contributes to improve the combustion, the cold starting of the engine and the acceleration performances.

The main characteristic that render bioethanol a biofuel worse than petrol is the energy density: considering the LHV values, for substituting a kilogram of petrol 1.67 kilograms of bioethanol are required.

In Table 2 the properties of bioethanol and diesel oil are compared in case of using this biofuel in the Diesel cycle engines with after perfectioning some aspects of the engine itself.

The bioethanol properties confer to this biofuel a behav-

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Bioethanol</th>
<th>Petrol</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV</td>
<td>MJ/kg</td>
<td>27</td>
<td>44</td>
</tr>
<tr>
<td>Oxygen content</td>
<td>% w/w</td>
<td>35</td>
<td>absent</td>
</tr>
<tr>
<td>MON</td>
<td></td>
<td>96</td>
<td>85</td>
</tr>
<tr>
<td>RON</td>
<td></td>
<td>130</td>
<td>95</td>
</tr>
<tr>
<td>Octane number</td>
<td></td>
<td>113</td>
<td>90</td>
</tr>
<tr>
<td>Boiling temperature</td>
<td>°C</td>
<td>78</td>
<td>100</td>
</tr>
<tr>
<td>Vapour pressure</td>
<td>kPa</td>
<td>124</td>
<td>85</td>
</tr>
<tr>
<td>State</td>
<td></td>
<td>Liquid</td>
<td>liquid</td>
</tr>
<tr>
<td>Aspect</td>
<td></td>
<td>Limpid</td>
<td>limpid</td>
</tr>
</tbody>
</table>

Table 1: chemical and physical properties of bioethanol and petrol, mean values¹
The energy density of bioethanol is inferior than that of diesel oil, in fact 1.0 kilogram of diesel oil corresponds to 1.70 kilograms of bioethanol. Bioethanol evidences a quickness in the ignition inferior than that of diesel oil because of its low cetane number value. The flash point value is inferior if compared to that of diesel oil and for this reason bioethanol presents more difficulties in the transport, manipulation and storage phases.

### 6.2 Production

Bioethanol can be produced from different raw materials, and as a consequence of the chosen material can be classified in first, second or third generation biofuel.

#### 6.2.1 First generation bioethanol

Bioethanol of first generation is the ethanol produced from sugary or starchy raw materials derived from dedicated crops or agri-food industry residues.

The dedicated crops can give materials whose utilization is specifically referred to the bioethanol chain because of their high content of carbohydrates. In particular, the most important sugary crops are sugarcane, sweet sorghum, sugar beet; from these crops a sweet juice can be obtained and the simple sugars contained in this juice can be directly fermented to ethanol.

The most important starchy crops are cereals like maize, wheat, barley (i.e. the grains are used) but also cassava or other tuberous roots are used because of their high content of starch.

The agri-food industry residues that can be used for ethanol production derive from the fermentation of molasses, by-product of the sugar production chain, from the distilleries and wine industry (i.e. marcs and other grape residues), from the fruit juices production. These materials contain simple sugars that can be directly fermented to ethanol.

The process to obtain bioethanol from sugary and starchy crops is different.

The sugary chain for the bioethanol production has a plant processing structure that is simpler than the other chains because of the raw materials content of simple sugars (e.g. glucose, fructose, sucrose) that can be directly fermented to ethanol. The phase of extraction is necessary for obtaining the sugars contained in the stalk juice (i.e. sugarcane, sweet sorghum) or in the pulp of the crops (i.e. sugar beet). The extraction can be done or with mechanical roller mills to press the biomass or through a process of diffusion with warm water to solubilize the sugars in the solution.

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Bioethanol</th>
<th>Diesel Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV</td>
<td>MJ/kg</td>
<td>27</td>
<td>42</td>
</tr>
<tr>
<td>Oxygen content</td>
<td>% w/w</td>
<td>35</td>
<td>absent</td>
</tr>
<tr>
<td>Cetane number</td>
<td>-</td>
<td>27</td>
<td>48</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>13</td>
<td>72</td>
</tr>
<tr>
<td>Viscosity</td>
<td>cSt</td>
<td>0.5 (at 20°C)</td>
<td>2.6 (at 20°C)</td>
</tr>
<tr>
<td>State</td>
<td>-</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>Aspect</td>
<td>-</td>
<td>Limpid</td>
<td>Limpid</td>
</tr>
</tbody>
</table>

Table 2: chemical and physical properties of bioethanol and diesel oil.
The starchy chain is characterized by the necessity of transforming the starch in simple sugars for the fermentation. The reaction that allows this transformation is the hydrolysis made with specific enzymes.

Before this treatment is necessary a comminution of the material through milling or squeezing, then the hydrolysis takes place in two phases: the liquefaction phase, finalised to reduce the length of the starch chains using the alpha-amylase enzyme; then the saccharification phase finalised to the cut of simple sugars in the starch chains using the gluco-amylase enzyme. At the end, the broth is fermented to ethanol like in the sugary chain.

The fermentation is done for the sugar juices or produced sugar broths with yeasts that metabolize the sugars in ethanol and CO₂. The ethanol concentration is 9-14%.

The following process steps (i.e. distillation, rectification and dehydration of the ethanol) are the same for both chains. The fermented medium is distilled using some distillation columns (i.e. multiple effect distillation) made of bubbling dishes and the ethanol is collected at a concentration of 96.0%. Then, it is dehydrated to produce anhydrous bioethanol [99.7-99.8% w/w] in a dehydration unit based on molecular sieve technology made of zeolite, that retains selectively the residual water molecules.

Finally the pure ethanol can be mixed with fossil fuels for the transport use.

### 6.2.2 Second and third generation bioethanol

The lignocellulosic material can be used for bioethanol production because it is made of long structured chains of polysaccharides that can be hydrolysed in simple sugars to ferment. The lignocellulosic raw materials are more complex than the sugary and starchy ones mainly because of the structure of hemicellulose-lignin that wraps the cellulose chains.

The lignocellulosic raw materials can be dedicated energy crops like giant reed, miscanthus, switchgrass, fiber sorghum or short rotation forestry crops like poplar or other wooden crops.

Other lignocellulosic raw materials can be: crop residues (i.e. agriculture and forestry residues, like reported in Table 3), the organic fraction of the municipal solid waste, the residues of the public green like gardens and parks. Their valorisation results as strategic because they have a low market value and a big availability.

The lignocellulosic section for the production of bioethanol foresees more steps of processing because of the complexity of the material. In the cellular wall of the plants in fact hemicellulose and cellulose, that are convertible in bioethanol, are strongly structured with the lignin, not transformable in ethanol. For this reason a pretreatment for the disgregation of the cell wall structure and for disorganising the structure separating cellulose and hemicellulose from lignin is necessary, as shown in Figure 1.

<table>
<thead>
<tr>
<th>Crop residues</th>
<th>Average production [t/ha]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat straw</td>
<td>3-6</td>
</tr>
<tr>
<td>Wheat of other winter cereals</td>
<td>3-3.5</td>
</tr>
<tr>
<td>Maize stalks</td>
<td>4.5-6</td>
</tr>
<tr>
<td>Vine branches</td>
<td>3-4</td>
</tr>
<tr>
<td>Olive tree branches</td>
<td>1-2.5</td>
</tr>
</tbody>
</table>

Table 3: the average production of the crop residues
There are different typologies of pretreatment:

1. chemical pretreatments: acid or dilute acid pretreatment (i.e. with sulphuric acid or other acids), alkaline pretreatment (i.e. with sodium hydroxide or lime);

2. thermal pretreatments: steam explosion, saturating the biomass with water at high temperatures (180-230 °C) and in pressure (1.4-4.0 MPa) and then transferring quickly the biomass in a lower pressure reactor causing the break of cell walls;

3. thermo-chemical pretreatments: ammonia fiber explosion that combines the temperature, pressure and the use of ammonia, or the steam explosion using sulphurous anhydride;

4. biological pretreatments using specific microorganisms (Phanerochaete spp.) that degrade lignin.

After these pretreatments many inhibitor compounds are produced and for this reason a detoxification step is required. It can be carried out in two phases: one at pH values of 10-11 for precipitating the inhibitors, then a second one at pH 6 filtering the insoluble inhibitors with 0.2 µm filters.

The following phase is the enzymatic hydrolysis of the obtained cellulose and hemicellulose. This hydrolysis can be carried out using commercial enzymes (i.e. endocellulases, exocellulases) produced from filamentous fungi like Trichoderma spp. or Fusarium spp. that are able to degrade these polymers in single sugars to ferment. From the cellulose the hexose sugars with 6 atoms of carbon (e.g. glucose) are obtained and from hemicellulose the pentose sugars with 5 atoms of carbon (e.g. xylose) are obtained. These sugars can be fermented in bioethanol using specific yeasts. For the hexoses, like in the sugary or starchy chain Saccharomyces cerevisiae is used, while for pentose sugars commonly Pichia spp. are used because they are able to metabolise this kind of sugars with their specific metabolic pathways.

6.3 Utilisation

One of the most important applications of biofuels is the use in thermal engines, that means in the machines with the purpose of transforming the thermal energy in mechanical energy.

The thermal engines can have an external combustion, when the combustion occurs out of the engine fluid, or an internal combustion when the biofuel is burnt in the fluid itself. The internal combustion engines, called also endothermic engines, are the most diffused in terms of installed units. Among them can be found the Otto cycle engine, that work with petrol, the Diesel cycle engine and the gas turbine.

Biofuels were utilised in the endothermic engines since the first phases of development of these machines. Already in the first years of 1900 the vegetable oils were used in the Diesel engines, while the first more in-depth studies were carried out in the 1920’s. The interest for this type of fuels increased during the Second World War.
to face the lacking of fossil fuels.

Since the War to nowadays, nevertheless, the technological development has brought to a use almost exclusive of fossil fuels; the engines, moreover, have been enormously improved, most of all for what concerns the injection and control systems, in a way that has rendered them not much flexible for the use with fuels different from Diesel and petrol.

The increased attention to the environmental impact of the combustion processes has newly renewed the interest towards biofuels and the implications that their utilisation can have from technical and economical points of view in the engines.

In this paragraph the analysis of these implications in relation to the Otto engines and the use of bioethanol is presented. The principle of functioning of the most diffused endothermic engines is described and in particular the engine components, whose functioning can be influenced by the utilised biofuel, are examined.

**Internal combustion engines**

The engines with internal combustion are thermal machines that convert in mechanical work the chemical energy of the fuel. Their names derives from the fact that the energy transformation takes place inside the engine and not outside, in specific parts like burners.

The internal combustion engines can be subdivided in different categories following different indications:

- modality of ignition: engines with controlled ignition or ignition with spark commonly called Otto cycle engines, and spontaneous ignition engines or with compression called also Diesel cycle engines;

- duration of the functioning cycle: two-stroke engines whose operating cycle is done just in one turn of the driving shaft that means in two runs of the piston, and four-stroke engines whose operating cycle is done in two turns of the driving shaft that means four runs of the piston.

The internal combustion engines are characterized by the presence of a combustion chamber of variable volume, whose geometry is defined by the alternate movement of the piston. This one is connected through a rod to the driving shaft, also called crankshaft and it moves between two extreme positions called superior dead point and inferior dead point; in correspondence of them the volume of the chamber reaches respectively the minimum and maximum values. The cylinder is put in communication with the external environment through specific aspiration and discharging valves that are opened at each cycle and allow the turnover of the work fluid.

The Otto cycle engines have a cylinder where a mixture of air and fuel is compressed; this mixture is lighted through a spark caused by a candle in the last moments of the compression phase. In order to have a good engine functioning it is very important that the fuel does not light spontaneously as a consequence of the high temperatures present in the cylinder (i.e. detonation). This problem can be avoided limiting the compression ratio. The compression phase must be taken into consideration for the Otto cycle engines and for this reason the compression ratio at maximum can be 12:1 – 13:1. The engine performance is proportional to the
compression ratio and for this reason the Otto cycle engine has lower conversion efficiencies if compared with other engines. In the Otto cycle engines the regulation of the load quantity introduced in the cylinder occurs through a valve called butterfly valve that causes some losses of load in the feeding circuit.

The advantages of the Otto cycle engines
In the Otto cycle engines the pressure in the cylinder is not so high and the mechanical stress is low on the structure. The combustion releases a lower amount of carbon deposits if compared to other engines avoiding the degradation of the lubricant oil (lower maintenance is required). The levels of harmful emissions of the Otto cycle engines are lower too.

For the engines that operate with variable number of revolutions (e.g. engines for the cars), it is very important the progress of the couple correlated with the variation of the number of revolutions and also with the value of the maximal power. The influence of the environmental parameters and in particular the temperature must be taken into consideration.

The use of alternative fuels in the engines cannot leave out of consideration a verification of the injection system compatibility. This verification can be done just on the basis of a deep knowledge of the system and of course must be done in collaboration with the car/engines manufacturer.

The systems of Otto cycle engines feeding
In the engines with controlled ignition, mainly two feeding systems are used:
- the carburation that exploits the depression inside of a Venturi duct to call back the amount of fuel which is necessary in the air flow aspirated from the descendent movement of the piston;
- the injection (direct or indirect) that means the fuel injected under pressure in the aspirated air mass.

With the sole exception of the direct injection systems, the preparation of the air-fuel mixture starts outside the cylinders and it is completed inside the combustion chamber.

The quickness of formation and the mixture homogeneity depend on different functioning and constructive parameters of the engine, like for example the rotation speed, the load, the fuel characteristics, the geometry of the ducts and the valves arrangement.

The quality of the air-fuel mixture can be defined through the dosage that means the ratio in air-fuel mass. When in the case of petrol engines this ratio corresponds to 14.7 the mixture is called stoichiometric; for higher values is called “thin” and for lower values is called “rich” or “fat”. Using a thin mixture is possible to get better efficiencies while in a certain extent a rich mixture allows to reach higher powers. For a catalyzed engine the optimal functioning of the catalytic converter requires the maintaining of the stoichiometric dosage: nevertheless, in some functioning conditions, for example during the cold start, the mixture is enriched. This involves a temporary increase of the polluting emissions. In the field of cars/road transport the introduction of catalytic converters implied the use of electronic injection in substi-
tution of the carburettor in order to ensure a precise control of the mixture quality.

In the indirect injection systems the quantity of necessary fuel for obtaining the correct dosage can be injected in the air flux during the aspiration phase from a single injector positioned before the butterfly valve (i.e. single point injection) or the injection can be done with more injectors, one per each cylinder, positioned before the aspiration valve (i.e. multi-point injection). Basing on the strategy of injectors command, the multi-point injection can be:

- simultaneous: when the injectors introduce contemporaneously the fuel, requiring just one command from the control unit;
- semi-sequential: when different groups of injections are activated just with one command; in this way the control system is simplified;
- sequential: when the single injector is operated singularly following a precise order.

The necessity of further reducing the pollutant emissions of the petrol and Diesel engines brought at the end of 90’s to the realization of engines with stratified loads with the adoption of direct injection. In both systems, direct and indirect injection, the regulation of the injected quantity and of the mixture quality is done intervening on the opening time of the injectors.

**Bioethanol and Otto cycle engines**

Bioethanol is a valid and concrete alternative to petrol and can be used pure (i.e. E100), or in blendings, generally in the proportion of 10% bioethanol and 90% petrol, or 85% bioethanol and 15% petrol (i.e. E85). The presence of a small percentage of petrol is necessary to allow the cold start because below 10-15 °C the ethanol evaporates with difficulty not allowing the start of the combustion; this disadvantage can be solved using a heater.

The high octane number of bioethanol allows the improving of the engine performances because the risk of detonation is reduced. The octane number is an index that characterises the amount of antiknocks in a petrol: higher its value, higher the resistance to detonation. The detonation is an anomalous combustion that consists in the auto-ignition of the air-fuel mixture before the reaching of it from the flame front. After the detonation, pressure waves are created: they are shock waves that move at the sound speed in the combustion chamber and generates a specific noise called “spark knock”. The detonation decreases the engine efficiency and if it is of relevant entity can damage the mechanical components like pistons and head.

Bioethanol, nevertheless, has a heating value 40% lower than petrol and this corresponds to an increase of consumptions of about 35% and a small reduction of the performances if there is no intervention on other functioning parameters like the injection duration and the ignition anticipation.

The potential risks connected to the use of bioethanol are caused by the corrosion phenomena; the feeding system for this reason must be realised using preferably stainless steel of compatible rubbers.

The lubricant properties of bioethanol, moreover, are lower than the petrol ones and therefore for some components (e.g. the valve seats) must be used more re-
sistant materials. Today, all engines are predisposed in order to work with petrol containing limited percentages of bioethanol (up to 5% - 10% in volume) to follow the EU Directives.

In connection with the attainable environmental balances, the use of bioethanol in the Otto cycle engines allows performances comparable to those of petrol (see Table1).  

### The environmental benefits and the emissions

The strategic role of bioethanol in particular must be connected to the environmental benefits that can be obtained. Most of all its contribution on the carbon dioxide balance is almost zero if produced from agri-residues or wastes or is low with dedicated crops. Another important aspect is that the use of bioethanol for the cars contributes to improve the air quality in the city centres and in the main big roads. Bioethanol in fact has a higher oxygen content if compared to that of petrol, allows a more complete combustion with a significant containing of the emissions of CO, particulate, NOx and VOC like shown in Table 4.

### 6.4 EU strategies for biofuels and RES

The interest of the EC in the utilisation of RES in transport, electricity and heat sectors is testified by numerous Directives. For reasons of synthesis, this chapter is aimed to collect only the main documents about the transport sector, because the considered chain is aimed above all to satisfy the increasing demand of biofuels in the EU. The European biofuels market has enjoyed excellent EC support by way of the Kyoto Agreement as well as Directives 2003/30/EC and 2003/96/EC, which are specifically aimed to promote the increased use of biofuels and set indicative targets for their use in the transport industry.

The Directive 2003/30/EC of 8th May 2003 “on the promotion of the use of biofuels or other renewable fuels for transport” laid the foundation for the promotion of alternative fuels in the EU. In particular, it specified that Member States should ensure that a minimum share of biofuels and other renewable fuels is placed on the market and, to that effect, shall set national indicative targets.

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**Table 4: average production of the crop residues**

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<tr>
<th>Pollutants emissions</th>
<th>CO</th>
<th>NOx</th>
<th>SO2</th>
<th>PM</th>
<th>VOC</th>
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<td>Bioethanol 10 % v/v1</td>
<td>-5</td>
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<td>-18</td>
<td>-46</td>
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<td>Bioethanol 20 % v/v2</td>
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<td>-25</td>
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<tr>
<td>Bioethanol 85 % v/v3</td>
<td>-23</td>
<td>-50</td>
<td>-93</td>
<td>-70</td>
<td>-58</td>
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</table>
Reference values for these targets were given, as calculated on the basis of energy content, namely:

- 2% of all petrol and diesel for transport purposes placed on their markets by 31st December 2005;
- 5.75% of all petrol and diesel for transport purposes placed on their markets by 31st December 2010.

The Directive aimed at increasing the share of renewable energy in the transportation sector (currently dominated almost entirely by fossil fuels) and reducing emissions of CO$_2$, CO, NO$_x$, VOC and other particles harmful to human health and the environment.

In accordance with this Directive, the different types of biofuels are as follows: bioethanol, biodiesel (diesel-quality methyl ester produced from biomass or used vegetable oils and used as biofuel), biogas (fuel gas produced from biomass and/or waste by anaerobic fermentation, purified to natural gas quality), bio-methanol, bio-dimethyl-ether, bio-ETBE, bio-MTBE, synthetic biofuels (synthetic hydrocarbons or mixtures of synthetic hydrocarbons produced from biomass), bio-hydrogen, and oil produced from oil plants by pressing, extraction or comparable procedures, crude or refined but chemically unmodified, when compatible with the type of engines involved and the corresponding emission requirements.

Biofuels may be made available in any of the following forms:

- as pure biofuels or at high concentration in oil derivatives, in accordance with quality standards for transport applications;
- as biofuels blended in mineral oil derivatives, in accordance with the appropriate European norms describing the technical specifications for transport fuels (EN 228 and EN 590);
- as liquids derived from biofuels, such as bio-ETBE where the percentage of biofuel is 47% w/w.

The Directive 2003/96/EC of 27th October 2003 has been focused mainly on the tax applied over the biofuels. This Directive modified the Community Tax for the energetic products and power. In this Directive the following aspects have been established:

- art. 16.1: the Member States can apply the exemption or reduced tax over the biofuels;
- art. 16.3: the exemption or reduction of the tax can be modulated in function of the evolution of the price of the raw materials;
- art.16.5: the application period is of six years, although this period can be pro-rogued until before 31/12/2012.

This Directive allowed applying the exemption or reduction of the tax since 1st January 2003 (art. 28.2)

The Directive 2009/28/EC of 23rd April 2009 indicates an updated objective for the reduction of the GHGs emissions in the transport sector:

- 10% of the final consumption must be covered with RES within 2020.

Furthermore, the RED introduces for the first time a reduction target for the GHGs emissions from biofuels:
o the GHGs emissions saving due to the use of biofuels shall be at least 35%;
o with effect from 1st January 2017, the GHGs emissions saving from the use of biofuels shall be at least 50%;
o from 1st January 2018, the GHGs gas emissions saving shall be at least 60% for biofuels produced in installations in which production started on, or after, 1st January 2017.

These goals have been combined with specific sustainability requirements for biofuels, in response to controversy surrounding their environmental impact, the price of foodstuffs and the loss of biodiversity. All the biofuels that do not offer the minimal GHGs emissions saving (e.g. 35% at the present time), when their whole LCA is considered compared to petrol or diesel will not be included in the goals and will not grant public aid.

Furthermore, the RED takes paints to list the types of land that must not be planted with biofuels crops, namely natural forests, protected areas, wetlands and peat bogs.

The RED includes the “standard default values” for the main biofuels (Annex V, Part A). The calculation includes CO$_2$, CH$_4$ and N$_2$O, which are both more powerful GHGs than CO$_2$.

The Member States must notify to the EC of the geographic areas where the mean GHGs emissions savings by biofuel crop type are lower than these standard values. Besides the RED specifies the method to calculate the GHGs emissions saving in the specific cases, when the standard default values can not be used (Annex V, Part C).

In order to certify the sustainability of biofuels, the introduction of voluntary certification systems could also guarantee data compliance with sustainability criteria. On 27th May 2011 the EC officially recognised the first seven voluntary certification schemes: “Greenenergy Brazilian Bioethanol Verification Program”, “Bonsucro EU”, “Abengoa RED Bioenergy Sustainability”, “Roundtable of Sustainable Biofuels EU RED”, “International Sustainability and Carbon Certification”, “Biomass Biofuels Voluntary Scheme”.

Furthermore the RED indicates that the development of the RES must be united to the increase of the energy efficiency as an aim for reducing the GHGs emissions in the EU. In fact the increase of 20% in the energy efficiency from now to 2020 is another essential objective of the RED.

Further objectives and applications of the RED are the following:
o to establish a common framework for the promotion of the energy obtained by RES;
o to fix the obliged national objectives related to the energy production from RES in the final consumption of the energy and related with the renewable energy for the transport;
o to establish the norms of statistics transference among the Member States, the common projects among the Member States and with outside, the origin guarantees, the administration procedures, information and formation and the access to the power net for the renewable energy.
The Directive 2009/30/EC of 23rd April 2009 aims at improving air quality and reducing GHGs emissions through environmental standards for fuel. It will also facilitate the more widespread blending of biofuels into petrol and diesel and, to avoid negative consequences, set ambitious sustainability criteria for biofuels.

The revised Directive indicates that by 2020 fuel suppliers must decrease by 6% cli-

**TOPIC: THE EU SUSTAINABILITY CRITERIA FOR BIOFUELS IN ACCORDANCE WITH THE RED**

The sustainability is required equally to biofuels produced in the EU and to the imported ones.

Furthermore, only the sustainable biofuels are counted to reach the target to 2020 and can benefit from eventual national incentives.

The sustainability of biofuels is ensured complying with all of the following criteria:

1. GHGs emissions saving attributed to each biofuel shall be at least 35% since 2012, 50% since 2017, 60% since 2018;

2. biofuels shall not be made from raw materials obtained from land with high biodiversity value, namely land that had one of the following statutes in or after January 2008, whether or not the land continues to have that status:
   - primary forest and other wooded land, named forest and wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;
   - areas designated:
     - by law or by relevant competent authority for nature protection purposes;
     - for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature, subject to their recognition;

   unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;
   - highly biodiverse grassland that is:
     - natural, named grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes;
     - non-natural, named grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded, unless evidence is provided that the harvesting of the raw material is necessary to preserve its grassland status;

3. biofuels shall not be made from raw material obtained from land with high carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status:
   - wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;
   - continuously forested areas, namely land spanning more than one hectare with trees higher than five meters and a canopy cover of more than 30%, or trees able to reach those thresholds in situ;
   - land spanning more than one hectare with trees higher than five meters and a canopy cover of between 10% and 30%, or trees able to reach those thresholds in situ;

4. biofuels shall not be made from raw material obtained from land that was peatland in January 2008, unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously undrained soil.

The Directive 2009/30/EC of 23rd April 2009 aims at improving air quality and reducing GHGs emissions through environmental standards for fuel. It will also facilitate the more widespread blending of biofuels into petrol and diesel and, to avoid negative consequences, set ambitious sustainability criteria for biofuels.

The revised Directive indicates that by 2020 fuel suppliers must decrease by 6% cli-
mate-harming emissions over the entire LCA of their products. This can be reached in particular by admixing biofuels to petrol and diesel as well as by improving production technology in refineries. Member States may require an additional 4% reduction from fuel companies, achieved through the supply of energy for electric vehicles or other clean technologies, including carbon credits from third (so-called “Clean Development Mechanism”).

To enable these GHGs emissions cuts, petrol may have higher biofuel content. From 2011, petrol may contain up to 10% (v/v) bioethanol. In order to avoid damage to old cars, however, fuel with 5% (v/v) bioethanol will continue to be available until 2013, with the possibility for Member States to extend that period.

The Directive also incorporates the same environmental and social sustainability criteria for biofuels as in the RED. It imposes limits on the content of sulphur and metallic additives in engine fuel. Finally, the maximum vapour pressure of fuel is also prescribed in order to minimise emissions of volatile air pollutants. The revised environmental quality standards as well as the sustainability criteria for biofuels are applied since 2011.

Member States are required to transpose the Directive into national law by the end of 2010.

A recent document of the EC (i.e. Accompanying document to the Communication from the Commission to the European Parliament and the Council {COM(2011)31 final} of 31st January 2011) has assessed the national financing of RES in the Member States and the European strategies to achieve the target to 2020. The situation for the national financing is reported in Table 5.

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</table>

Table 5: national financing of RES in Member States
In the transport sector a mixture of instruments is used to support the development of RES, chiefly biodiesel and bioethanol. Quota systems require the use of biofuels for a given fraction of the road transport fuel mix. The fuels themselves are freely tradable across the EU. The extra cost of the biofuel is then part of the price of petrol or diesel and passed on to consumers. In 17 Member States this quota regime is supplemented by tax credits, whereby expenditure on biofuels is tax deductible. This supplement is therefore additional support funded by taxpayers. The empirical evidence regarding this sector shows that biofuels growth is more effective in those Member States where both instruments are applied.

In the electricity market, 21 Member States now use FIT at least for some technologies and some market segments; 7 Member States use feed in premiums and 6 use quotas. The use of multiple instruments or the adaptation of instruments also reflects the efforts to improve the efficacy of the instrument in a gradual manner without causing too much disruption to the market. Changes in recent years have seen a blurring of the traditional dichotomy of tradable certificates (setting quantity not price) and FIT (setting price not quantity). The most part of the Member States have continued to focus on national resources and could achieve their 2020 targets on their own. Historically, Member States have been keen to develop their own resources (contributing to their own emissions reductions, reducing fossil fuel imports and generating jobs) rather than develop the cheapest renewable energy sources. However, as the cheaper renewable energy potentials are exploited and costs start to rise, the need to seek out cheaper RES in other Member States will rise.

In the heating sector in Member States there has been the predominance of investment grants for installation of small solar thermal or solar photovoltaic units. The scope for any large scale heating from RES is only now beginning to be explored in most Member States, partly because it is only now included in the European regulatory framework (i.e. the 20% target). Projects could include developing combined heat and power plants and/or district heating systems based on geothermal, biogas or biomass energy sources.

As regards with the evolution of the electricity market, it will benefit from some cooperation mechanisms introduced by the RED, that allow a cross-financing between Member States for the achievement of the EU target:

- **statistical transfers**: these are agreements between Member States to transfer a quantity of renewable energy produced in one Member State to another Member State for target compliance purposes. The transfer is purely virtual; there is no accompanying energy flow. This mechanism exists so that Member States with considerable renewable energy sources, or with effective support schemes that help develop such sources cost effectively, can offer any renewable energy production surplus to their requirements (either to their target or trajectory) to other Member States. The other Member States interested in purchasing such transfers would be those with limited domestic renewable energy sources or with inadequate support schemes for developing the available domestic resources. The transfers would normally be for Member States wanting to comply with their targets, or until their own domestic resources can be brought into production at a later stage;

- **joint projects**: this is a help to build new plants and infrastructure in a Member State, sharing the resulting energy towards two or more Member States' national targets,
in order to reduce the overall cost of reaching the targets. One key difference between joint projects and statistical transfers is the proposed inclusion of “private entities” in joint projects. A private entity such as a power generator, infrastructure company, energy equipment manufacturer, a banking consortium can identify projects in any Member State. Financing such a project could occur under the normal and existing domestic arrangements, but if such arrangements are insufficient, because the support is too low or does not qualify according to domestic priorities, the project would not be built. In such a case, the project developer could broker an agreement whereby another Member State agrees to help finance the project; again, this could be through loans, grants, tenders or access to national support schemes such as FiT or Green Certificate regimes. In exchange for this co-financing, the Member State would receive credit for a share of the renewable energy that was produced as a result of the project.

In addition to the cooperation mechanisms available to Member States, the RED also has created an instrument that would enable third countries to take part in developing renewable energy sources and contributing to the EU target. Accordingly, joint projects between Member States and third countries (similar in structure to the joint projects between Member States) can be established. However, whilst joint projects between Member States can be purely virtual trade arrangements, joint projects with third countries have strict conditions attached to them to ensure that the arrangements generate new renewable energy production of electricity that is actually consumed in the EU. The energy that is produced and exported to the EU under the agreement may not receive operating support. This rule is applied to reduce the risk of paying double subsidies and over-compensating producers;

- **joint support scheme:** the Member States may agree to join or coordinate their national support schemes (e.g. a common FiT or Green Certificate/obligation regime). In the event of the joining of schemes, the renewable energy produced under such conditions is considered “pooled” and shared out either as a “statistical transfer” or according to an agreed distribution rule.

It is plausible that with these mechanisms the cost of achieving the targets whilst promoting the growth and future prosperity of the European renewable energy industry can be minimised.

**Topic: The Indirect Land Use Change (ILUC)**

The ILUC is the potential impact due to the expansion of the agricultural lands to cultivate food and animal feed crops, as consequence of the cultivation of biofuels crops in agricultural lands to comply with the sustainability criteria of the RED. This expansion might decrease the lands with high natural carbon stocks being converted for food and animal feed and consequently it might influence the GHGs emissions balance.

Compared to the direct LUC, which occurs when a new activity has settled in an area of land, the ILUC cannot be directly observed and measured.

The EC is assessing the opportunity to consider the ILUC in the sustainability criteria of biofuels. At this aim the EC has launched a public consultation procedure to debate the subject and the models that could be used.

The options considered by the EC are:

- take no action for the time being, while continuing to monitor: this option would maintain the RED in its current form but potentially would introduce a means of monitoring the ILUC impacts of biofuels. Taking the decision not to introduce additional policy
Bioethanol consumption, production and market in the EU

Caused by the target of the RED and likely also caused by the recent increase of the share of bioethanol in blending with petrol (i.e. 10% v/v), the bioethanol consumption in the EU has significantly raised in 2010 compared to 2009: + 26.1% (Table 6).

6.5 Bioethanol consumption, production and market in the EU

Caused by the target of the RED and likely also caused by the recent increase of the share of bioethanol in blending with petrol (i.e. 10% v/v), the bioethanol consumption in the EU has significantly raised in 2010 compared to 2009: + 26.1% (Table 6).
### Table 6: Consumption of Bioethanol in the EU in 2009 and 2010 (in toe)\(^\text{16}\)

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Greece</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Italy</td>
<td>118,014</td>
<td>139,940</td>
<td>+21,926 +18.6%</td>
</tr>
<tr>
<td>Spain</td>
<td>152,347</td>
<td>233,179</td>
<td>+80,832 +53.0%</td>
</tr>
<tr>
<td>Germany</td>
<td>581,686</td>
<td>746,775</td>
<td>+165,089 +28.4%</td>
</tr>
<tr>
<td>France</td>
<td>410,404</td>
<td>490,112</td>
<td>+79,708 +19.4%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>160,505</td>
<td>316,495</td>
<td>+155,990 +97.2%</td>
</tr>
<tr>
<td>Poland</td>
<td>150,000</td>
<td>187,184</td>
<td>+37,184 +24.8%</td>
</tr>
<tr>
<td>Austria</td>
<td>64,488</td>
<td>63,457</td>
<td>-1,031 -1.6%</td>
</tr>
<tr>
<td>Sweden</td>
<td>198,183</td>
<td>203,943</td>
<td>+5,760 +2.9%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>137,360</td>
<td>134,136</td>
<td>-3,224 -2.3%</td>
</tr>
<tr>
<td>Belgium</td>
<td>42,392</td>
<td>52,119</td>
<td>+9,727 +22.9%</td>
</tr>
<tr>
<td>Portugal</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Romania</td>
<td>53,274</td>
<td>45,142</td>
<td>-8,132 -0.15%</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>48,326</td>
<td>61,262</td>
<td>+12,936 +26.8%</td>
</tr>
<tr>
<td>Hungary</td>
<td>46,972</td>
<td>57,615</td>
<td>+10,643 +22.7%</td>
</tr>
<tr>
<td>Slovakia</td>
<td>39,983</td>
<td>45,142</td>
<td>+5,159 +12.9%</td>
</tr>
<tr>
<td>Finland</td>
<td>75,451</td>
<td>73,517</td>
<td>-1,934 -2.6%</td>
</tr>
<tr>
<td>Ireland</td>
<td>23,241</td>
<td>27,324</td>
<td>+4,083 +17.6%</td>
</tr>
<tr>
<td>Lithuania</td>
<td>14,091</td>
<td>10,412</td>
<td>-3,679 -26.1%</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>740</td>
<td>720</td>
<td>-20 -2.7%</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1,859</td>
<td>2,904</td>
<td>+1,045 +56.2%</td>
</tr>
<tr>
<td>Cyprus</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Denmark</td>
<td>6,238</td>
<td>34,179</td>
<td>+27,941 +447.9%</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Latvia</td>
<td>1,120</td>
<td>8,419</td>
<td>+7,299 +651.7%</td>
</tr>
<tr>
<td>Malta</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Estonia</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>2,326,675</td>
<td>2,933,977</td>
<td>+607,302 +26.1%</td>
</tr>
</tbody>
</table>

Table 6: Consumption of Bioethanol in the EU in 2009 and 2010 (in toe)\(^\text{16}\)

### Table 7: EU Bioethanol Plants\(^\text{17}\)

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Plants</th>
<th>Raw Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>4</td>
<td>Barley, wheat, raw alcohol, maize, lignocellulose</td>
</tr>
<tr>
<td>France</td>
<td>12</td>
<td>Sugar beet, sugar juice, wheat, glucose, raw alcohol</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1</td>
<td>Cereals</td>
</tr>
<tr>
<td>Belgium</td>
<td>2</td>
<td>Cereals</td>
</tr>
<tr>
<td>Germany</td>
<td>3</td>
<td>Cereals, sugar juice</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1</td>
<td>Wheat</td>
</tr>
<tr>
<td>Austria</td>
<td>1</td>
<td>Wheat</td>
</tr>
<tr>
<td>Hungary</td>
<td>1</td>
<td>Maize</td>
</tr>
</tbody>
</table>

Table 7: EU Bioethanol Plants\(^\text{17}\)
Taking into consideration this trend, it is plausible that the countries that have yet to achieve their biofuels goals will drive the European growth in coming years.

Concerning the European bioethanol production, the amount of bioethanol produced in 2010 has been of 4.3 million tonnes with an increase of 13.3% compared to the value of 2009 (i.e. 3.8 million tonnes).

The EU bioethanol demand (i.e. 2.93 million toe) exceeds the supply (2.75 million toe) and consequently the importations contribute significantly to the consumed amounts.

As regards with the European bioethanol market, the traditional importing countries are Brazil and the US.

Brazilian imports have almost plummeted to the point of no-return. In fact Brazil is finding it hard to meet the demand of its own domestic FFV market for bioethanol, because the number of these vehicles forms the core of the new registrations and it is rising all the time. Furthermore, in view of the very high world prices, Brazil is encouraging sugarcane exports.

On the contrary, currently the US bioethanol is available for the importation in the EU, because the US supply exceeds the demand. The surplus of bioethanol in the US market constitutes a risk of dumping through the exportation of the blend E90, which benefits from a tax reduction higher than that of the pure bioethanol. This situation is going to change, caused by the forthcoming increase in the share of bioethanol in blending with petrol in accordance with the RFS: at the present time the blend E10 is distributed but in short term the blend E15 will be used in the vehicles put into service since 2001 with a consequent decrease in this surplus of E90.

A significant share of the programmed increase in bioethanol fuel requirements prompted by the RED should revert to European output.

6.6 National strategies in the consortium countries

Basing on the indications of the EU, each Member State has issued laws and decrees in order to make effective at national level these strategies. The treatment of the national legislative instruments is tackled in every country of the consortium in the following paragraphs, where also the national conditions for the viability of the model are explained.

6.6.1 Italy

National Action Plan (NAP)

In accordance with the indications of the RED, in June 2010 the NAP, where the Italian strategies to achieve the targets to 2020 are planned, has been drawn up.

As regards with the national objective for the share from RES of the total consumption (i.e. 17%) compared to 2005, the NAP has assumed that the total energy consumptions in 2008 and 2020 will be equal approximately caused by the increase in the energy efficiency of the plants and buildings and by the drop in consumptions due to the economic crisis. Then, basing on the total energy consumption of 2008 (i.e. 131 Mtoe), the share from RES of 17% (i.e. 22 Mtoe) has been assigned to the different sectors (i.e. electricity, heat, transport) as reported in Table 8.

The same assumptions have been applied to plan the achievement of the specific target for the transport (i.e. 10%) (Table 9).

The NAP has established in detail the contribution of every RES to the achievement
of the total targets. The sharing among the RES is shown in Table 10 for electricity, in Table 11 for heating sector and in Table 12 for the transport one.

As regards with the transport sector, in accordance with the indications of the RED, the 2nd generation biofuels benefit from the double counting and the amount of electricity in the on-road transport is multiplied by the coefficient 2.5 in order to reach the target of 10%.

Analysing the contents of the NAP, the following strategies are evident:
- the promotion to the CHP systems for the burning of biogas and bioliquids;
- the preferential use of wood in the heating sector, instead of in the electricity one;
<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2020</th>
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<tbody>
<tr>
<td></td>
<td>Production</td>
<td>Share of the total RES</td>
</tr>
<tr>
<td>Geothermal</td>
<td>23</td>
<td>1.19%</td>
</tr>
<tr>
<td>Solar</td>
<td>27</td>
<td>1.43%</td>
</tr>
<tr>
<td>Wood</td>
<td>1,629</td>
<td>84.99%</td>
</tr>
<tr>
<td>Biogas</td>
<td>26</td>
<td>1.35%</td>
</tr>
<tr>
<td>Bioliquids</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other heat pumps *</td>
<td>212</td>
<td>11.04%</td>
</tr>
<tr>
<td>Total</td>
<td>1,917</td>
<td>100%</td>
</tr>
</tbody>
</table>

* with exception of geothermal pumps

### Table 11: contribution of every RES to the heat production to reach the target to 2020 (in ktoe)

<table>
<thead>
<tr>
<th>RES Description</th>
<th>2005</th>
<th>2020</th>
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<tbody>
<tr>
<td></td>
<td>RES counting for the target 10%</td>
<td>Share of total consumption</td>
</tr>
<tr>
<td>1st generation bioethanol + Bio-ETBE</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2nd generation bioethanol + Bio-ETBE</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Imported bioethanol + Bio-ETBE</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1st generation biodiesel</td>
<td>158</td>
<td>46.65%</td>
</tr>
<tr>
<td>2nd generation biodiesel</td>
<td>21</td>
<td>12.30%</td>
</tr>
<tr>
<td>Imported biodiesel</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electricity in road transport</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electricity in non-road transport</td>
<td>139</td>
<td>41.05%</td>
</tr>
<tr>
<td>Other biofuels</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>318</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Table 12: contribution of every RES to the transport sector to reach the target to 2020
• the creation of district heating networks fed with RES (e.g. wood, CHP plants using biogas or bioliquids);
• the increasing contribution of the geothermal source in the heating sector;
• the relevance of biofuels to respect the objective to 2020: especially the contribution of biodiesel will cover the 62.3% of the RES and bioethanol the 20.5%;
• the basic role of the importation of biofuels (both biodiesel and bioethanol) to reach the target of 10%.

The NAP indicates the main instruments for adopting these strategies.

Concerning the electricity sector, the rationalisation of the incentive system is necessary. In fact, at the present time the instrument depends on the specific RES. For example for the solar source the FIT is used, whereas for plants supplied with biomass, biogas and bioliquids and power up to 1 MWe two incentives are available: the all-inclusive tariff (with values stable for 15 years) and the Green Certificates multiplied by a specific coefficient. In addition the feedstock supply through the short chain (i.e. maximum distance 70 km) is further rewarded increasing the multiplying coefficient.

As regards with the heating sector, the current White Certificates appear not efficient in rewarding the investments and the NAP suggests to reinforce this instruments for applications with a payback inferior to 10 years and with a significant improvement in the energy saving. On the contrary currently the main incentive to promote the reduction in use of fossil fuels in this sector is the tax deduction of part of the costs (i.e. 55%) for interventions aimed to improve the energy efficiency (e.g. condensing boiler, solar thermal plant).

In the transport sector the quota obligation is the system which has been applied in the creation of the biofuels market: in fact, increasing shares of biofuels must be distributed every year; on the contrary an administrative penalty is applied to the fuels distributors. The shares fixed are: 4.0% for 2011, 4.5% for 2012.

**Legislative decree n. 28 of 3rd March 2011 and attached implementing decrees**

The legislative decree 2011/28 acknowledges in Italy the RED and defines the scenario to implement the strategies of the NAP.

As regards with the biofuels, the decree has introduced two important elements: the share for 2014 has been fixed in 5.0% and the application of the sustainability criteria of the RED will enter into force in Italy since 2012.

In particular, concerning the sustainability of biofuels, the decree has modified the national market, making competitive only the sustainable biofuels because they are the only ones to be counted to reach the target to 2020.

Furthermore, to achieve this objective a special counting system has been foreseen:
• biofuels produced in the EU processing national feedstock are counted with an increased share: +10%, basing on the energy content (i.e. 1 certificate is attributed for 9 Gcal of distributed biofuel);
• biofuels distributed outside the network and mixed with 25% petroleum products are counted with an increased share: +10%, basing on the energy content (i.e. 1 certificate is attributed for 9 Gcal of distributed biofuel);
biofuels produced from wastes, by-products, no-food feedstocks, included cellu-
losic and lignocellulosic raw materials and algae, are rewarded with the double
counting: + 100%, basing on the energy content.

The modalities to access to the increases foreseen in this decree for the sustainable
biofuels will be explained in the attached implementing decree, which is being issued.
The implementing decree will give careful indications about the traceability in the
biofuels chains, in order to know in detail all the traders (i.e. fuels distributors, feed-
stock suppliers) and to provide the instruments to verify compliance with the sustain-
ability criteria until the final trader. Furthermore, the implementing decree will list the
by-products, which access to the double counting to reach the target to 2020.
As regards with the electric sector, the decree establishes since 2015 the termination
of the Green Certificates and since 2012 the introduction of the a new system, where
are integrated an all-inclusive tariff and an incentive fixed through an auction.
The value of the all-inclusive tariff is specific for each source and for echelon of
power, which in any case can not be less than 5 MWe.
The plants which do not access to the all-inclusive tariff benefit from an incentive,
fixed by GSE as the lowest value in Dutch auctions, with a minimum recognized in
any case. The auctions are recurrent and special for each source and range of
power or for every type of plant. The participation in each auction is subjected
to comply with some minimum requirements, such as the financial strength of the
proposer and the economic viability of the initiative, and with specific mechanisms
to ensure the actual realisation of the plant, such as the deadline for the start date.
Both incentives are combinable with:
- public incentive covering at maximum the share of 40% of the investment costs:
o for power up to 200 kW for all the RES;
o for power up to 1 MW for plants installed in farms or managed by farms, cattle
farms, farms forestry, food companies, and supplied with biogas, biomass or sus-
tainable bioliquids;
o for CHP or CCHP plants for solar source or biomass or biogas, which are obtained
from agricultural or forest products, manure, included by-products, in the context
of specific agreements among the chain actors or through short chain (range of
supplying up to 70 km);
- public incentive covering at maximum the share of 30% of the investment costs:
o for power in the range 200-1,000 kW for all the RES (with the previous exceptions);
- public incentive covering at maximum the share of 20% of the investment costs:
o for power in the range 1-10 MW for all the RES (with the previous exceptions).

The modalities to access to these incentives will be explained in the attached im-
plementing decree, which is being issued.
In particular the following indications will be detailed: the values of the all-inclusive
tariff for each RES and the related range of power, the values for the incentives
given through the Dutch auctions (e.g. minimum value recognized in any case),
the parameters to grant the proposers to the auctions, the way to pass from the
old incentive system to the new one, the calculation to define the production from
RES in hybrid power plants.
Concerning the heating sector, two supports are foreseen: for the smaller interventions the contribution pursuant to the tariff for the natural gas, for the bigger ones the issue of White Certificates.

The contribution pursuant to the tariff of the natural gas is aimed to reward the investment costs for the improving of the energy efficiency and for the reduction in the use of fossil fuels. This incentive is suited to the obtained energy saving and its value is constant for all the duration (i.e. maximum 10 years). The applied mechanism suggests that this incentive is similar to the FIT used in the electricity sector.

The White Certificates, foreseen also by the previous incentive system, have been boosted and the procedures have been simplified. In particular their duration and value have been adjusted respectively to the lifetime and the cost of the intervention.

Furthermore a guarantee fund has been established for realising the district heating networks.

The modalities to access to these incentives will be explained in the attached implementing decree, which is being issued.

The main indications, which will be given, are: the values and duration of the contribution pursuant to the tariff of the natural gas, the threshold value to distinguish between small interventions and big ones, the minimal technical requirements to access to the incentives (in terms of efficiency, quality of emissions, quality of biomass), the accumulation of different incentives, the values and duration of the White Certificates.

Furthermore, the legislative decree 2011/28 contributes to regulate the authorisation procedures for the realisation and the operation of plants supplied with RES.

In accordance with the Directive 2001/77/EC the principle applied in the Italian law foresees the simplification and the acceleration of the authorisation practices related to the plants supplied with RES, in order to promote the development of this sector and to contribute the achievement of the targets to 2020.

The legislative decree n. 387 of the 29th December 2003 has acknowledged the Directive 2001/77/EC and the realisation and operation of these are subjected to the “single authorisation”. In accordance with this decree the competence in granting the “single authorisation” lies with the regional administrations, which can delegate to another institutional body (e.g. Province, Municipality).

In accordance with the legislative decrees 2003/387 and 2011/28 the “single authorisation” process has the following steps:

- submission of as “single authorisation” to the regional administration (or delegated institutional body);
- within 30 days: convening of the Conference of the services, in which representatives of all local administrations (e.g. Provinces and Municipalities), Regional Agency for the Environmental Protection, electric utilities and local health participate. In the Conference of the services the technical and environmental aspects of the initiative are discussed and eventual information and data are required to the proposers. If the submission of “single authorisation” for many plants in the same region happens, the assessment of each one is carried out considering the cumulative effect of the initiatives;
• within 90 days (at maximum 180 days): granting of the “single authorisation”. In this period is not counted the time for the eventual EIA. The granting of the “single authorisation” allows to start the works to realise the plant and afterwards it allows to start the operation of the plant.

For power inferior to 200 kWe or 250 kWe in case of biogas, the “single authorisation” is not required, but the “authorized simplified procedure” is sufficient. At this aim the application is submitted to the interested Municipality. In accordance with the Legislative Decree 2011/28 the regional and provincial administration can extend this range of power up to 1 MWe.

The Italian law does not require the IPPC for energy plant with power within 50 MWe. The reference law is the legislative decree n. 59 of 18th February 2005, which has acknowledged the Directive 1996/91/EC (IPPC Directive).

In the attached implementing decree will be listed the interventions qualified as substantial change of existing plants, which shall be subjected to the single authorisation.

All the implementing decrees, attached to the legislative decree 2011/28, are drafted through the cooperation among MSE, MIPAAF and MATTM and they issue within the end of 2011.

*Legislative decree n. 55 of 31st March 2011*

The legislative decree 2011/55 increases the amounts of bioethanol in blending with petrol (i.e. 10% v/v, blend E10) and completes the scenario defined by the legislative decree 2011/28 about the GHGs emissions saving consequent the utilisation of biofuels.

The decree establishes that at the beginning of every year the fuels distributors shall declare to the MATTM the GHGs emissions and the energy content correspondent to the distributed fuels (fossil fuels and biofuels). In particular, as regards with the biofuels, they shall certify their sustainability in accordance with the RED and Directive 2009/30/EC.

For the calculation of the GHGs emissions saving and related sustainability, the decree acknowledges in Italy the methods for the calculation of the GHGs emissions saving of biofuels, in accordance with the Annex V of the RED.

*National conditions for the viability of the model*

As regards the viability of the EU model in Italy, basing on the current situation, the following remarks emerge:

• bioethanol produced from sweet sorghum is insufficiently supported by the current incentives (i.e. +10%) and it is not competitive if compared to the 2nd generation one (+100%);

• the reward of electricity produced from bagasse of sweet sorghum and from vinasse is promising, because it can benefit from the all-inclusive tariff, which ensures fixed market conditions and reduces the business risk. The values of the all-inclusive tariff for each RES are being determined and they could confirm this remark;

• the reward of heat is promising through the White Certificates, about which the forthcoming decree will determine the values and duration.
Consequently the EU model is consistent with the Italian strategies for using RES in the electricity and heating sector, whereas this statement is not really correct for the 1st generation bioethanol.

It is important to underline that the current situation is not completely clear, because some important variables persist at the present time: especially the values for the all-inclusive tariff and White Certificates can influence significantly the economic viability of the model. The current situation should be definitively cleared within the end of 2011.

6.6.2 Greece

In 2002 the Greek national law regulating matters relating to Greek oil policy was announced as law n. 2002/3054 "Organization of petroleum products market and other provisions (FEK A' 230/2.10.2002)".

The provision of services and any other activity linked to the refining, marketing, transport and storage of crude oil and mineral oil products is subjected to the provisions of the present law and shall serve the general interest. The exercise of any activity relating to refinement, distribution of biofuels, marketing, retailing, transport of mineral oil products through a pipe and bottling of LPG shall be subject to the granting of a correspondent authorization.

The Directive 2003/30/EC was adopted by the Hellenic legislative framework on December 13th 2005 by putting into force law n. 2005/3423 "Introduction onto the Greek market of biofuels and other renewable fuels" as it was amended by law n. 2008/3653 (Article 55)18. These specific laws defined the Greek national strategy for biofuels aimed to bring the share of biofuels and other renewable fuels in the Greek market to 5.75% of the total petrol and diesel consumed in the transport sector by December 2010. According to law n. 2008/3653 (Article 56) the introduction of bioethanol into the market is envisaged for the period 2010-2016. The use of direct bioethanol into gasoline is not considered suitable for Greek climate therefore its convention to bio-ETBE is proposed.

The law n. 2005/3423 completes the law n. 2002/3054 and sets the base for the disposal of biofuels through a system for allocating quantities of biodiesel. By joint decision of the Ministers of finance, development, rural development and food it was established a program of distribution of biodiesel in quantities. In particular, Article 15A of this law and the law n. 2009/3769 with Articles 21 and 22 provide the tools for the strategic development of energy crops in Greece, establishing the distribution system of biodiesel among the potential producers.

The Greek law n. 2010/3851 (OG A/85/4th June 2010) "Accelerating the development of RES to deal with climate change and other regulations in topics under the authority of the Greek Ministry of environment, energy and climate change" sets the Greek REP in the scope of the RED.

Specifically, the law n. 2010/3851 sets specific targets for RES electricity share (40%), RES heating and cooling share (20%), and RES transport share (10%), in order to achieve the national target of 20% contribution of the energy produced from RES to the gross final energy consumption.

After 8 years of European Directive implementation, bioethanol plants are yet to be installed. This fact along with the existing legislation implies that the construction
of such units could be crucial. The Greek Sugar Company had expressed its interest to convert two of its existing sugar factories in Larissa and Xanthi to bioethanol production plants, along with simultaneous production of high nutritive quality fodder, electricity and heat, with annual capacity of 150,000 m³ bioethanol each. The raw materials would be beet, grain and corn crops, which are already common in Greece and production could be initiated within 18-24 months after the beginning of works, eventually starting by the end of 2009 or the beginning of 2010. The Greek Sugar Company launched a competition to attract a strategic investor in 2007. In 2008, two offers from two different investors, Motor Oil Hellas and Cal West Ethanol & Renew Energy EU LLC, were announced. The international competition was however cancelled in November 2010 without being completed.

Annual biomass production from agricultural residue in Greece is estimated at 5 million tons of dry biomass per year, a production that equals to 2 million toe. According to data from the Oil Policy Directorate of the Ministry of Development the annual demand for domestic fuel, oil has surpassed 4 million tons. Proper utilization of the produced biomass can cover up to 60% of domestic fuel annual demands, the percentage covered is nevertheless only 3% of the annual energy demands\(^{19}\).

Currently is under development the harmonization of the Greek institutional framework, and more specifically of the law n. 2002/3054, to the Directives 2009/28/EC and 2009/30/EC.

On July 2011 the Ministry for environment, energy and climate change established a working group to draft implementing regulations on the introduction and promotion of bioethanol as a fuel in the Greek territory under the provisions of Article 15A (10) of the law n. 2002/3054 (GG 230 A) as applicable. The working group is constituted of 24 members, representatives of various public and private parties such as:

- Ministry of environment, energy and climate change
  - Directorate of Oil Policy, General Secretariat for Energy and Climate Change
  - Directorate of Supervision and Management of Oil Products
  - Directorate of Oil Products Facilities
  - Investors Service for RES projects
- Ministry of finance
  - Directorate of Excise duties
  - D29 Directorate of Alcohol, alcoholic, beverages, wine, beer
  - D28 Directorate of Petrochemicals
- Ministry of infrastructure, transport and networks
  - Directorate of Vehicle Technology
- Ministry of rural development
  - Directorate of Tobacco, Aromatic and Medicinal Plants
- Ministry of development, competitiveness and shipping
  - Directorate of Development and Coordination
- Centre for renewable energy and saving
The objective of the working group is to introduce the promotion of bioethanol as fuel in the Greek territory in a mixture with petrol or through conversion into petrol components. More specifically, the group will investigate a complexity of issues relating to: the importation, supply, production, sale, distribution, the minimum of blending, technical specifications, taxation and monitoring of the tax base, and will recommend specific institutional interventions in order bioethanol to be entered in the Greek market in accordance with the provisions of Article 15A, (10) of the law n. 2002/3054 (GG 230 A) as amended and in effect to Article 22 of the law n. 2009/376 (Official Gazette A 105) and accordance with the objectives of the RED. The working group is going to complete its work within four months of its establishment.

*Milestones to be set for the introduction and promotion of bioethanol as fuel in the country*

1. Utilization of domestic resources (raw material producers of energy crops or biomass) from domestic units with multiple benefits for the national economy and security of supply.

2. Energy production from local or regional small and medium-sized businesses, as they have a positive impact on social cohesion, on export prospects, on job opportunities and opportunities for regional and local development.

3. Use of technological advances to ensure the reduction of production costs and incensement of energy efficiency.

These objectives can be served by measures of internal policy, that may correspond to the respective applicable for biodiesel such as:

1. indirect support of the production within the Greek territory from domestic or foreign investors who will use the raw materials produced by Greek farmers, appropriate energy crops (e.g. sweet sorghum, maize);

2. support (indirect subsidy) of contracted agriculture (with long or short term contracts aside) to provide the raw material exclusively by Greek farmers;
3. financing of investment for production of bioethanol including to either the expansion of units already operating as biodiesel production plants or establishing new plants from domestic or foreign investors;
4. development of small and medium-sized bioethanol plants located near the centers of feedstock production and port facilities;
5. establishing a minimum percentage of bioethanol blending in transportation fuels;
6. establishing the obligation of the refineries to absorb the bioethanol produced;
7. introduction of tax incentives for bioethanol producers.

**Example of indirect support for the development of energy crops in country’s system for the production and distribution of biodiesel (a) & (b)**

<table>
<thead>
<tr>
<th>Allocation of biodiesel to the plants</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Contracts for biodiesel production with farmers that cultivate energy crops within the Greek territory</td>
<td>25%</td>
</tr>
<tr>
<td>b) Purchase invoices and/or accounting data supply cottonseed and/or cotton</td>
<td>5%</td>
</tr>
<tr>
<td>c) Invoices for supply of raw materials derived from used vegetable oils and animal fats with Greek origin, suitable for producing biodiesel</td>
<td>7.5%</td>
</tr>
<tr>
<td>d) Capacity of biodiesel plant established in a Member State of the EU or import contracts intact biodiesel established in another Member State of the EU</td>
<td>20%</td>
</tr>
<tr>
<td>e) A certificate issued or the contract award to obtain ISO 9000 series on production and/or full text available biodiesel</td>
<td>5%</td>
</tr>
<tr>
<td>f) The offered by the applicant company, a maximum premium</td>
<td>10%</td>
</tr>
<tr>
<td>g) Existing cooperation agreements with research institutions and organizations or contracts to participate in research projects within the EU on issues related to biofuels and biomass</td>
<td>5%</td>
</tr>
<tr>
<td>h) All the supplies of biodiesel in kiloliters, on allocations of the previous two years</td>
<td>15%</td>
</tr>
<tr>
<td>i) The index of consistency of supplies of, on the breakdown of last year, the refineries</td>
<td>7.5%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Table 13: allocation of biodiesel quantities to the biodiesel plants*
As regards with the authorisation process, terms and formalities concerning the production, distribution, blending and release for consumption of biodiesel have been issued with a Joint Ministerial Gazette n. 2006/1757. The respective conditions for bioethanol have not been published yet.

Excluded from the obligation to obtain a license to produce electrical energy or any other certification decision are physical or legal persons, who produce electrical energy is biofuel stations with installed electrical capacity smaller than or equal to 1 MW.

Exempt from the obligation of publication of the “Approval of Environmental Conditions” decision are the stations producing electrical energy from RES installed in field courts, as long as their installed electrical capacity does not exceed 0.5 MW for stations producing electricity using biofuels.

**National Renewable Energy Action Plan (NREAP)**

In the scope of the RED, in July 2010 has been drawn up the NREAP; this report has been compiled under the supervision of the National Committee for Meeting 20-20-20 Targets and Other Requirements (“20-20-20 Committee”).

The table of the Figure 2 presents the estimation of total contribution expected from each renewable energy technology in Greece to meet the binding 2020 targets and the indicative interim trajectory for the shares of energy from renewable resources in the transport sector 2010-2020.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioethanol/Bio-ETBE</td>
<td>-</td>
<td>43</td>
<td>142</td>
<td>171</td>
<td>198</td>
<td>226</td>
<td>256</td>
<td>287</td>
<td>316</td>
<td>346</td>
<td>380</td>
<td>414</td>
</tr>
<tr>
<td>Of which imported</td>
<td>-</td>
<td>43</td>
<td>142</td>
<td>171</td>
<td>198</td>
<td>226</td>
<td>256</td>
<td>287</td>
<td>316</td>
<td>346</td>
<td>380</td>
<td>414</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>1.2</td>
<td>64</td>
<td>69</td>
<td>83</td>
<td>97</td>
<td>123</td>
<td>150</td>
<td>175</td>
<td>190</td>
<td>203</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renewable electricity</td>
<td>-</td>
<td>2.4</td>
<td>3.3</td>
<td>4.0</td>
<td>5.1</td>
<td>6.2</td>
<td>7.2</td>
<td>8.3</td>
<td>9.4</td>
<td>12.1</td>
<td>14.5</td>
<td>16.5</td>
</tr>
<tr>
<td>Of which road transport</td>
<td>-</td>
<td>0.7</td>
<td>0.7</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
<td>1.3</td>
<td>1.4</td>
<td>1.4</td>
<td>3.3</td>
<td>4.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Of which non-road transport</td>
<td>-</td>
<td>1.7</td>
<td>2.6</td>
<td>3.2</td>
<td>4.1</td>
<td>5.0</td>
<td>5.9</td>
<td>6.9</td>
<td>7.8</td>
<td>8.8</td>
<td>10.0</td>
<td>11.4</td>
</tr>
<tr>
<td>Total</td>
<td>1.2</td>
<td>110</td>
<td>214</td>
<td>258</td>
<td>300</td>
<td>345</td>
<td>393</td>
<td>441</td>
<td>486</td>
<td>534</td>
<td>584</td>
<td>634</td>
</tr>
</tbody>
</table>

**Figure 2:** estimation of total contribution expected from each renewable energy technology in Greece (biofuels that are included in Article 21(2) of Directive 2009/28/EC)

The comparison of the basic results for the final energy consumption, the RES contribution and the amount of RES installations required is given in more detail in the table of Figure 3.

**Sustainability criteria for biofuels and bioliquids implemented at national level**

There is no specific legislation for the implementation of sustainability criteria for biofuels and bioliquids presently under consideration. The introduction of sustainability criteria at national level is planned to be carried out through legislative alternatives that include:

- additions amending law 2009/3769, so that all quantities of biofuels placed on the domestic market meet the sustainability criteria of the RED;
- use of the invitations to participate in the quota allocation of pure biodiesel – terms and conditions for the verification of compliance with sustainability criteria. Note that under Article 15A (10) to (11) of 2009/3769, the supply of bioethanol
and other biofuels in the Greek market is determined by JMDs which may cover sustainability criteria;
- issuance of a JMD as specified in Article 15A par. 12 of 2002/3054.

A final decision on the instrument that will implement such sustainability criteria for the biofuels and the bioliquids is not taken yet.

**National conditions for the viability of the model**

Greece has enforced the Directive 2003/30/EC by passing the national law 2005/3423, which enables the production, import and trading of biofuels. Up to date Greece does not produce bioethanol; in the country there are thirteen industrial plants and three enterprises that produce and import respectively biodiesel. Greece has managed to reach the EU target and substitute the 5.75% of diesel with biodiesel but still lags in the production of bioethanol to substitute the same percentage of petrol/gasoline consumption, which in 2009 was 4,376,240 toe.

The RES play a major role in the country’s evolving energy make-up. Biomass and bio-

<table>
<thead>
<tr>
<th>RES installed capacity [GW]</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference</td>
<td>Compliance</td>
<td>Accelerated economic recovery</td>
</tr>
<tr>
<td>Electricity production [TWb]</td>
<td>58.86</td>
<td>58.86</td>
<td>58.86</td>
</tr>
<tr>
<td>% RES electricity production</td>
<td>7.84</td>
<td>7.84</td>
<td>7.84</td>
</tr>
<tr>
<td>Of which biomass/biogas</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Of which hydro (excluding pumping)</td>
<td>2.54</td>
<td>2.54</td>
<td>2.54</td>
</tr>
<tr>
<td>Of which wind</td>
<td>1.33</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td>Of which solar photovoltaic</td>
<td>0.18</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>Of which CSP</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Of which geothermal</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Of which biomass/biogas</td>
<td>1.01</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>Of which solar heat</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Of which geothermal</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Of which ambient heat</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Of which biofuels in transport</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>% RES in gross final energy consumption</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
</tr>
</tbody>
</table>

*Figure 3: summary of results for energy consumption and RES utilization for the three basic scenarios examined for the compilation of the Greek NREAP*
fuels have been identified as strong market components with high growth potential. Three main success factors that may affect the profitability of a bioethanol chain are:

- the Government legal framework and supporting policies
- the sustainability of the feedstock supply
- the availability of the latest technology

To ensure the financial viability of the bioethanol plants, incentives by the Government should be provided. The major costs in biofuel production are the fuel taxes imposed by the Government, which in case of Greece correspond to the amounts given in Table 14.

In addition to the incentive provided by the exemption of the taxes on biofuels, all the legal issues shall be addressed in such a way that new investors, in order to be motivated to proceed with the plants, must be able to deal with less bureaucracy issues. Unfortunately, many cases are known regarding investments in the field of RES exploitation for the production of either electricity or thermal energy that have not been realized due to bureaucracy problems.

For the sustainability of the feedstock the following issues should be addressed. First, the farmers should be assured via contract agreements that they will sell their entire crop at a fixed price which will ensure their profit. Research has shown that sweet sorghum has low needs in water and fertilizers and farmers have a higher economic initiative in cultivating this energy crop since the sugar content per hectare of sweet sorghum cultivation is higher in comparison to other crops. Still many organizations/institutions are working in the improvement of the sweet sorghum productivity and tests of new varieties and hybrids are currently under way.

Another issue is the location of the plant. It is said that for the sustainability of the biomass, the collection centers should not be placed further than 30 km from the plants. There are different arrangements that may take place between the plant owners and the farmers, apart from the known one which is the sale of the crop (stalks and grains) to a plant. Independent farmers and/or farmer associations may proceed to the extraction of the juice and sell only the juice to the plant and as the extracted juice should be fermented immediately after the extraction the distance of the plant from the juice extraction unit should not be far. Another arrangement is that farmer associations ferment also the extracted juice and sell it to a distillation plant.

Examining the profitability of the EU model for the bioethanol production using sweet sorghum, labour costs should be also taken into consideration, as in non-EU countries (e.g. India) where such kind of plants exist labour costs are much lower. On the other hand, Investors should be assured that the fuel distilleries will buy all their bioethanol production at an advantageous price. If all the above aspects could be defined and the latest technology was available in each country,
the bioethanol market could be enhanced and the defined EU targets could be reached. By using the latest technology it is possible to improve the ethanol yield and reduce costs.

It is estimated by the World Bank that investment of more than 30 billion euro will be required by 2020 in the upgrade and building of power plants, in transmission and distribution, and the RES.

In Greece, the agricultural sector accounts for more than 5% of GDP, more than three times the EU average of 1.8%. Companies involved in biomass and biofuels will therefore find abundant sources of raw materials. In addition, the binding commitments of the Greek Government to replace 10% of current transport fuels with biofuels by 2020 translates into measurable opportunities within the next decade.

The main advantages of investing in biomass and biofuels in Greece are:

• abundant raw materials
• agricultural sector equals 5.2% of GDP vs 1.8% (i.e. EU average)
• high FiT for biomass, whose values guaranteed for 20 years are:
  o 200 €/MWh for power inferior to 1 MW
  o 175 €/MWh for power from 1 MW to 5 MW
  o 150 €/MWh for power higher than 5 MW;
• binding national commitments in biofuel use
• favorable, long-term legislative framework, ensuring investment reliability

Provisions regarding wholesale prices of petroleum products

According to law 2010/3851 the prices of petroleum products available in the national market are set freely throughout the entire state by those who practice the trade of these products.

For reasons of competition protection, the owners of a Refining License and a License for Distribution of Biofuels are obligated to inform the Minister of economic development, competitiveness and shipping as well as the R.A.E. the manner by which the ex factory prices of petroleum products are established.

The companies trading petroleum products are under the same obligation for what concerns the real prices (including possible discounts and other arrangements) at which they sell their petroleum products to the petrol stations in each area.

Investment law 2011/3908

The submission of investment plans is done in two time periods per year (April and October)

The main contents of the law are:

• the defined annual budget, making clear the allocation of financial resources so investors may plan accordingly;
• the guidelines for all sectors of the economy, except for those expressly provided for in Article 2 of the law;
• specified and fixed application deadlines (April and October).

Furthermore this law:
• is mindful of scarce public funds by providing incentives primarily through tax exemptions: for each euro of subsidy provided, three euros of tax exemptions are provided;
• provides for binding schedules, electronic submission, investment monitoring and new Investor Service Offices that assist investors;
• introduces a new evaluation process by establishing the National Register of Evaluators and Auditors;
• focuses on sustainable investment projects that are environmentally friendly, promotes innovation, regional cohesion, youth entrepreneurship and create jobs.

Investment categories:
1. General Entrepreneurship
   Target Group: all enterprises irrespective of sector.
   Provides: tax breaks of up to 100% of the maximum allowable amount of aid.

2. Regional Cohesion
   Target Group: investors with projects that address local needs or capitalize on local competitive advantages.
   Provides: all forms of aid. The subsidy rate and leasing subsidy may reach up to 70% of the maximum allowable amount of aid. For new enterprises this percentage is increased by 10 percentage points.

3. Technological Development
   Target Group: enterprises that invest in innovation and want to upgrade their technology infrastructure.
   Provides: all forms of aid. The rate of subsidy and leasing subsidy may reach up to 80% of the maximum allowable amount of aid.

4. Youth Entrepreneurship
   Target Group: investors from 20-years to 40-years old.
   Provides: aid for virtually all costs (including operational) for five years from the start of the business. Total aid may reach up to 1,000,000 €.

5. Large Investment Plans
   Target Group: investments with a budget of at least 50,000,000 €.
   Provides: all forms of aid, either in one form or a combination of forms. The level of aid decreases as the amount of investment increases. The percentage of the subsidy may not exceed 60% of total aid.

6. Integrated, Multi-Annual Business Plans
   Target Group: companies legally formed at least five years previous to application, to implement integrated multi-annual (2-5 years) business plans with a budget of at least 2,000,000 € in total.
   Promotes: technological, administrative, organizational and business modernization. 100% of the maximum regional aid applicable shall be granted.

7. Partnerships and Networking
   Target Group: partnerships and networking configurations or clusters. These clusters shall be comprised of at least ten enterprises in the Region of Attica and the Thes-
<table>
<thead>
<tr>
<th>Region</th>
<th>Prefecture Zone</th>
<th>Large enterprises</th>
<th>Medium-size enterprises</th>
<th>Small and micro enterprises</th>
</tr>
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<tbody>
<tr>
<td>South Aegean</td>
<td>Cyclades C</td>
<td>15%</td>
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<td>Sterea Ellada</td>
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<td>Viotia A</td>
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<td>Pella C</td>
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<td></td>
<td>Imathia C</td>
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<td>Pieria C</td>
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<td></td>
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<td>Corfu C</td>
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<td>Samos C</td>
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<tr>
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<td>Xanthei C</td>
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<td>Rodopi C</td>
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<td>Drama C</td>
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<td>Thrеспотия C</td>
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<tr>
<td>Western Greece</td>
<td>Achaea C</td>
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<td></td>
<td>Etolo-Akarnania C</td>
<td>40%</td>
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<td></td>
<td>Ilia C</td>
<td>40%</td>
<td>45%</td>
<td>50%</td>
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</tbody>
</table>

Table 15: regional state aid map and aid rates for each prefecture
saloniki Prefecture and of at least five enterprises in other prefectures, operating in the form of a consortium.

Provides: for any form of aid.

Types of aid:

A. **Tax relief**: tax relief comprising exemption from payment of income tax on pre-tax profits which result, according to tax law, from any and all of the enterprises activities.

B. **Subsidy**: gratis payment by the State of a sum of money to cover part of the subsidized expenditure of the investment.

C. **Leasing subsidy**: includes payment by the State of a portion of the installments paid under a leasing agreement executed to acquire new machinery and/or other equipment.

D. **Soft loans by ETEAN**: the amount to be covered by a bank loan may be funded by soft loans from credit institutions that cooperate with ETEAN enterprises.

The aid referred to above shall be aggregated for the purpose of determining the total amount of aid allocated to the investment project. In this case the benefit of the funding above is included in total aid, which may not exceed the limits delineated on the Regional State Aid Map (Table 15).

An Independent Service for RES is introduced by the Ministry of environment, energy, and climate change which will act as an "one-stop shop" and will be responsible for providing information to all potential investors who are interested in RES.

### 6.6.3 Spain

**National Action Plan of Renewable Energies (NREAP)**

According with the European Directives referred to the promotion of renewable energies, Spanish Government developed the National Action Plan of Renewable Energies of Spain, published on 30th June of 2010. This NREAP has been based on the RED, fixing Spanish objective on 20% of energy consumed from renewable energies in 2020 with a contribution of 10% from renewable energies in the transport sector.

The development of the regulation of the energetic activity promoted by the Directive has been described by the RD2007/661, where is included the writing of the National Plan of Renewables Energies (PER).

Although the NREAP and REP include all the renewable energies and the reduction on the energy consumption, there is a specific part for the promotion and regulation of the biofuels production and consumption. The National Action Plan for the biofuels promotions is based in...
the evolution of the production and consumption of biofuels until 2009 in Spain. The evolution of the production capacity in Spain has been increased in the last years until 4 million of tonnes of oil equivalent. Although this increasing on the production capacity, the consumption has not increased in the same form. In fact, the motivation of this consumption has been promoting through the ministerial order ITC/2877/2008 of 9th October, where is described the promotion of the biofuels use in the transport sector.

Considering this aspect on the production and consumption of biofuels in the transport sector, there are other tools to ensure the Spanish objective for 2020. The energetic efficiency has become very important, translating this importance in specific actions. On the transport sector, considering the impact of the actions over the quality of the air in cities and the social pressure, the impact on the consumption of energy has been fixed on 40%. Apart from this, there are specific actions to make more efficient the transport, mainly with a modification on the taxation for the transport, including an environmental part on it, or new energetic labelled, to try to promote the use of more efficient elements.

Apart from the last indications, there are other laws that have influence over the promotion or development of this sector, through environmental regulation, for example, as it is described on the Directive 2008/50/EC, where is indicated the air quality on the cities. Indirectly, this Directive is going to have an influence over the efficiency on the transport.

Other regulation made by Spanish Government to reduce the impact of the transport and ensure the objectives for 2020 is the bylaw 2009/443, that has fixed the emissions of CO₂ on the road transport on 95 gCO₂/km for 2020. The objective marked wants to be achieved including the promotion of electric cars and hybrids plugged until 10% of the total park of cars.

All the laws, bylaws, orders and so on, have been developed to achieve the global objectives for the renewable energy in Spain, fixed on the RED, and assumed by the Spanish Government. These objectives are shown in Table 16 and they include all the uses for the renewable energies.

| A) Share of energy from renewable sources in the final gross energy consumption in 2005 (S2005) | 8.7% |
| B) Objective for the energy share from renewable sources in the final gross energy consumption in 2020 (S2020) | 20.0% |
| C) Expected consumption of total energy, under corrected value, in 2020 (ktoe) | 97,041 |
| D) Expected quantity of energy from renewable sources for the objective 2020 (ktoe) | 19,408 |

Table 16: national overall targets for the energy share from renewable sources in the final consumption of gross energy for 2005 and 2020

Although the targets indicated before are calculated for all the renewable energies in Spain, there is a specific calculation for the energy in the transport sector, including power consumption in the transport, biofuels and so on.

This calculation is shown in Table 17.

In this document, the calculation of RES consumption has been done, but this cal-
calculation is not going to be achieved if there are no actions to promote the consumption and production in Spain.

In biofuels sector, there are specific actions to promote the consumption and production. These specific actions are shown in Table 18.

Apart from the last actions, there are other specific actions to ensure compliance of the requirements of articles 17 and 21 of the RED. Specifically, the biofuels must meet sustainability criteria. The ministerial order ITC/2877/2008 develops a mechanism to promote the biofuels use for the transport sector, indicating the minimum amount obliged and how to measure the amount sold and consumed. The article 7 of this order describes the requirements to accredit the biofuels sold and consumed in Spain.

The sustainability of the biofuels must be accredited, considering the quality, origin of the raw materials, and the environmental evaluation of the crops.

The circular 2009/2 of 26th of February from the NEC, is going to regulate the promotion of the biofuels use in transport, indicating in its article 7 the system to present the applications of certification for the biofuels sold or consumed. In this circular is indicated that the certification of sustainability for the biofuels will be required.

According to this circular, there will be described the traceability needed in the production chain of biofuels, from the crop to the sale of the biofuel, taking special attention to the inputs and outputs of the production, including; internal registers of input or output for each step of the chain, documents of certification along the chain, minimal period of time to maintain these registers.

In the order ITC/2877/2008, in the article 6, is designing to the NEC as the admin-

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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>A) Forecast consumption of renewable energy sources in the transport sector</td>
<td>366</td>
<td>1,802</td>
<td>1,833</td>
<td>1,927</td>
<td>1,950</td>
<td>2,477</td>
<td>2,695</td>
<td>3,004</td>
<td>3,209</td>
<td>3,416</td>
<td>3,624</td>
<td>3,885</td>
</tr>
<tr>
<td>B) Forecast consumption of power from renewable energy sources in the road transport sector</td>
<td>0.0</td>
<td>0.1</td>
<td>0.9</td>
<td>3.1</td>
<td>6.8</td>
<td>12.3</td>
<td>30.6</td>
<td>48.3</td>
<td>66.5</td>
<td>84.6</td>
<td>103.6</td>
<td>122.9</td>
</tr>
<tr>
<td>C) Forecast consumption of biofuels obtained from wastes, non-food cellulosic raw materials, lignocellulosic materials, in the transport sector</td>
<td>0</td>
<td>50</td>
<td>55</td>
<td>55</td>
<td>60</td>
<td>65</td>
<td>161</td>
<td>170</td>
<td>175</td>
<td>232</td>
<td>242</td>
<td>252</td>
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<tr>
<td>D) Forecast of the contribution of the Renewable Energy Sources (RES) to the transport sector for the target RES-T: (A)+(2.5-1)x (B)+(2-1)x C</td>
<td>366</td>
<td>1,852</td>
<td>1,890</td>
<td>1,987</td>
<td>2,020</td>
<td>2,560</td>
<td>2,902</td>
<td>3,247</td>
<td>3,484</td>
<td>3,774</td>
<td>4,022</td>
<td>4,322</td>
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</table>

Table 17: calculation of the renewable energy share in the transports (ktoe)
<table>
<thead>
<tr>
<th>Denomination of the action</th>
<th>Type of action</th>
<th>Expected result</th>
<th>Group and/or activity to which the action is intended</th>
<th>Existing or under project</th>
<th>Date for beginning and end</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of the technical specification for B30 and E85, and their inclusion on the biofuels quality legislation in Spain</td>
<td>Regulatory</td>
<td>Improve the biofuels quality control and increase the confidence on this sector</td>
<td>Industrial, petroleum and logistic sectors</td>
<td>Project</td>
<td>2010-2012</td>
</tr>
<tr>
<td>Design and implantation of AENOR system to ensure the quality on the biofuels production process</td>
<td>Regulatory</td>
<td>Improve the biofuels quality control and increase the confidence on this sector</td>
<td>Industrial, petroleum and logistic sectors</td>
<td>Project</td>
<td>2010-2012</td>
</tr>
<tr>
<td>Design and implantation of a control system of sustainability in all the production chain of the biofuels commercialized in Spain, according with requirements of the Directive 2009/28/CE of 23rd of April.</td>
<td>Regulatory</td>
<td>Enhance the sustainability analysis</td>
<td>Agricultural, industrial, petroleum and logistic sectors</td>
<td>Project</td>
<td>2010-2012</td>
</tr>
<tr>
<td>Maintenance and adaptation of the scheme of the obligatory use of biofuels in the transport faraway from 2010. At this moment until 2010 there is the Order ITC/2877/2008</td>
<td>Regulatory</td>
<td>Increase the biofuels demand</td>
<td>Agricultural, industrial, petroleum and logistic sectors</td>
<td>Existing Project</td>
<td>From 2008 2010-2020</td>
</tr>
<tr>
<td>Modification of the legislation over the special taxation that allows the use of biogas as biofuel in transport at similar conditions than bioethanol and biodiesel.</td>
<td>Regulatory</td>
<td>Diversification of the biofuels offer</td>
<td>Industrial, petroleum and logistic sectors</td>
<td>Project</td>
<td>2010-2011</td>
</tr>
<tr>
<td>National Program to support the technological development in the biofuel sector: 2G and biorefinery.</td>
<td>Regulatory-Financial</td>
<td>Improve the technological development</td>
<td>Industrial, petroleum and logistic sectors</td>
<td>Project</td>
<td>2011-2020</td>
</tr>
<tr>
<td>Actuation of the Administrations through the promotion of buying cars with guarantee to use of mixing of fuels with biofuels.</td>
<td>Regulatory-Financial</td>
<td>Increase the demand of biofuels</td>
<td>Administrations and automotive sector</td>
<td>Project</td>
<td>2011-2020</td>
</tr>
</tbody>
</table>

Table 18: specific actions on the biofuels sector25
istration responsible to expedite of the certificates for the biofuels, management of the certification mechanism, and supervision and control of the obligation for commercialising the biofuels.

On the other hand, in Spain, the law 2007/42 of 13th December, of the Natural heritage and the biodiversity, is indicating what is the biodiversity and how to conserve this biodiversity, as is indicated on the RED.

**Promotion of the use of renewable energy in transport: Support Systems**

In Spain there are several laws that promote the biofuels use. For example, the law 1998/34 indicates the annual aims of biofuels in the transport. These aims are mandatory since 2009, focusing the 5.83% in 2010.

To ensure these aims, the order ITC/2877/2007 establishes the promotion mechanism for the use of these biofuels in the transport sector, fixing minimum aims per product under the global aims indicated in the law 1998/34. Apart from this, this order makes flexible the accounting of the amount of biofuels sold or consumed and this order develops a certification system and payments that will be managed by the NEC. This promotion action allows ensuring in 2011 a 7% of biofuels in fuels and diesel.

The overall aims for the biofuels are 3.40% in 2009 and 5.83% in 2010. Apart from these aims, there are specific aims per product as shown in Table 19.

At this moment, in the order ITC/2877/2008 there is no specific promotion per technology or product, and there is no specific promotion of the biofuels under article 21, paragraph 2 of the RED.

Considering that this order has designed to the NEC to manage the Issuance of certificates, management and control of the obligatory of biofuels commercialization, the NEC published the circular 2009/2 where is established the mechanisms to promote the biofuels consumption, normative to control this production and consumption, and so on. This circular indicates that the NEC is authorised to make inspections to control the obligatory indicated in the order reported before.

Other alternative in Spain to promote the use of biofuels in the transport is the regulation of the biofuels use in vehicles of the Administration. The Council of Ministers developed in 22nd of May 2006, an inter-ministerial commission to include environmental aspects in the public procurements. This objective is fixed on the order PRE/116/2008, where is approved a plan for the Green Public Procurement from the State General Administration.

With the application of this order, the objective is to achieve in 2012 the 38% of biofuels in the total consumption of fuels by the mobile park of the State.

In Spain, apart from the obligations, there are other actions to promote the production and consumption of biofuels, mainly through financial help and public funding. The specific legislation that controls this financial help is the following:

- law 1992/38 of 28th of December of special tax;
• RD 1995/1165 which approved the bylaw of special tax;
• law 2002/53 of fiscal actions, administrative and the social order;
• RD 2003/1739 that modifies the bylaw of special tax approved on the RD 1995/1165 and in the RD 2000/3485;
• Law 2005/22 that include on the Spanish ordering legal the communitarian Directives to the taxation of the energy products and power;
• RD 2010/191 that modifies the special tax bylaw, approved by the RD 1995/1165.

In all these laws and RD, there are specific considerations for the tax applied to the biofuels. These are specific forms to promote the production of the biofuels in Spain.

For example, the special tax law for biofuels indicate that, until 31st of December 2012, shall apply to biofuels a special type of zero euros per 1,000 liters on the hydrocarbons’ tax. The special type shall be used only on the volume of biofuel used even when it is mixed with other products.

Whenever the comparative evolution of the production costs of petroleum products and biofuels will be recommended, the laws of the state budget may replace the zero by a tax rate of positive amount, not exceeding the amount of type tax applicable to the equivalent conventional fuel. It is a statutory scheme administered by the Department of customs and Excise tax agency.

On the other hand, eligibility within this support system is not related to the size of the agent that commercializes the biofuel.

**Tax exemption for biofuels pilot projects**

The special tax law provides that the production or import of biofuels which are intended for using as fuel will be exempted of special hydrocarbon’s tax, either directly or mixed with conventional fuels in the field of pilot projects for the technological development of less pollutants products.

Pilot projects shall be considered for the technological development of less pollutant products or the pilot projects limited in time focused on the production or use of the products to demonstrate the technical viability of their production or use, further excluding the industrial exploitation of the results thereof.

This is a voluntary scheme managed by the Department of customs and Excise of tax agency.

The special tax bylaw indicates that, once approved the exemption request, the management center issues the recognition agreement with the effect the waiver requested by stakeholders and not exceeding five years.

There is a maximum size established in the bylaw on special taxes related to the accreditation of the pilot project and it is limited to demonstrate the technical feasibility of their production or use. This condition is considered proven when the amount of biofuel produced does not exceed 5,000 liters per year.

**Evolution of the biofuels area in Spain**

The hypotheses to explain the expected development in the production and use of biofuels in Spain during the period 2011-2020 are the following:
• **Bioethanol and Bio-ETBE.** Consumption is expected to be nearly double, from 232 ktoe in 2011 to 400 ktoe in 2020. A major jump in consumption will occur around 2013, with the likely demise of the protective petrol and the generalization of the specification of petrol like E10. On the other hand, it is estimated that the important contribution of imports of bio-ETBE to the domestic bioethanol consumption observed in 2010 will be reduced in subsequent years until it disappears. This aspect will be ensured with the widespread incorporation in petrol of a direct blending of bioethanol and bio-ETBE. Regarding the consumption of bioethanol and bio-ETBE indicated in the Article 21.2, the information shown displays the expectation that at the end of the period 2011-2020 any projects of bioethanol production come to be commercial projects in Spain for the production of bioethanol from lignocellulosic materials or waste.

• **Biodiesel.** Also the biodiesel consumption is estimated to double in the time period corresponding to NREAP passing from 1,471 ktoe in 2011 to 3,100 ktoe in 2020. However, the growth rate is not expected uniform, until 2013 will be very small, and from there it will accelerate the development due to the specifications for mixtures labeled along with the expected success of the normalization of the B10. As for imports, which in 2010 is expected to represent more than 60% of domestic consumption, is expected a gradual decline over the next few years, before stabilizing at around 10% of total consumption during the second half of the period 2011-2020. Finally, regarding the consumption of biodiesel in article 21.2, the table displays the expectation exists that at the end of the period 2011-2020 will reach a level of use of used vegetable oils close to two thirds of the potential use of them.

• **Others.** The evolution of consumption of biofuels between 2011 and 2020, according to estimates made for the preparation of this plan also includes a small contribution of biofuels different than ethanol and biodiesel, to be considered during the second half of the period. Among these, those who are more likely to build an autonomous development on the future would be the biogas for transport, the HVO and the Bio-SPK for the aviation market, all of these technologies are in a very preliminary stage of development today.
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<td><strong>TOTAL</strong></td>
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<td>1,833</td>
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<td>3,209</td>
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Table 20: estimation of the total contribution expected of each renewable energy technology in Spain aimed at meeting the binding targets for 2020 and the indicative interim trajectory for the shares of energy from renewable resources in the transport sector 2012
7. SWEET SORGHUM AS ENERGY CROP

7.1 Why sweet sorghum? 26,27,28,29,30,31,32

The common name of “Sorghum” is applied to a wide range of genotypes, mainly from Sorghum bicolor (L.) Moench species, within the gramineous family (Poaceae). Under this name, five groups of varieties are recognized:

A. grain sorghums. Usually dwarf varieties (50-80 cm high), which are grown for grain. Grain sorghum is the 4th most important cereal crop in the world after wheat, rice and maize;

B. forage (or fodder) sorghums. Varieties used primarily as silage for livestock due to their high protein and fiber content;

C. fiber sorghums. Tall, fine stemmed and rich in cellulose and hemicellulose varieties;

D. broom sorghums. Varieties that exhibit inflorescences with long and elastic branches, mainly used for brooms;

E. sweet sorghums. Varieties with thick and long stalks and high content of sugars in the stem, mainly sucrose, which are easily fermentable into bioethanol.

All these sorghums share to a certain extent some physiologic characteristics as high photosynthetic rate or sensibility to photoperiod and temperature, and some morphologic characteristics as the common size of big grasses of the tropical origin. However, sweet sorghum, as commented, stands out because of a physiologic characteristic: its high capacity to accumulate sugars (non structural carbohydrates) in the stem. Therefore, in order to avoid any confusion, it is advisable to use the name sweet sorghum and not only sorghum for those varieties that accumulate sugars easily fermentable in the stems and consequently which are interesting for the production of bioethanol like other sucrose-containing feedstock (e.g. sugarcane, sugar beet).

Sweet sorghum is a C₄ pathway crop. Among other particularities, C₄ plants have a characteristic leaf anatomy, called “Kranz anatomy”, which gives special separation between the photosynthetic CO₂ fixation and the synthesis of assimilates - compounds produced by plants as a result of the photosynthesis and responsible for plant growth. This compartmentalization allows a higher solar radiation use and high photosynthetic efficiency of sorghum comparing to C₃ crops, more common in temperate regions of the world. Photosynthetic assimilation rate is especially remarkable in conditions of high solar radiation and water availability. Studies on the RUE of sweet sorghum conducted in South Europe have shown high values of RUE, explaining the high productivity of this crop when is grown in favourable conditions (temperature, solar radiation and water supply). Values between 3.10 in France and 4.96 in Spain have been reported.

Biomass yield of sweet sorghum ranges 40–110 tons of fresh matter per hectare per year. Dry matter content is 19-30% depending on the variety, crop conditions and harvesting date. At the end of the cycle stalks usually represent more than 75% of the final weight of the harvested biomass (on dry weight), although these values can be variable depending on the variety and can reach the 90%.

The sugars accumulated in the stalks of sweet sorghum are water soluble sugars easily fermentable, mainly sucrose and a certain amount of glucose and fructose. Juice concentration in the stems is 65–80%. Sugar content in the juice of the stems
is 9–15%. Sugar content in the fresh stem is 7.9–12.0%. At the harvesting date, sugar concentration in the stalks (on dry weight) may range between 20–45% (mostly is sucrose) depending on the cycle length.

Biomass yields of sweet sorghum, grown in non-limiting water conditions in mild Mediterranean climates, are included between 25–35 t db/ha. Assuming 75-85% wb stalk proportion, 40% sugar content and 0.591 litres of ethanol/kg sugar as conversion factor, the bioethanol production using sweet sorghum could reach 4,400–7,000 l/ha.

Sweet sorghum can be grown in a very wide range of soils and climates (tropical, sub-tropical and temperate regions). Although best yields are obtained from fertile, deep and well drained soils, it could be cultivated in worse soil conditions, shallowness or in soils with low organic matter content. pH range of soils where sorghum can grow well is also wide (5.0–8.5). Sweet sorghum is drought resistant (it has good water stress resistance) if compared to other tropical crops, it is water-lodging tolerant and shows a good adaptability to saline and alkaline soils. This wide adaptability allows sweet sorghum to be grown where other crops could not be cultivated.

As regards to the water requirements, under Mediterranean conditions, sweet sorghum needs to be irrigated, but its water use efficiency is very high. Values between 3.7 and 5.4 g aerial biomass (db) per litre of water were reported for Spain. Sweet sorghum shows a higher drought resistance than maize or sugarcane (low evapotranspiration and the ability to stop transpiration if water is limited) and thus it requires less water per unit of ethanol produced. The quantity of water needed by sweet sorghum is only 1/3 of that required by sugarcane and almost 2/3 of sugar beet needs. Furthermore, sweet sorghum has relatively lower nitrogen needs than other crops.

Sweet sorghum is easily grown from seeds (3.0–6.0 kg seeds/ha), which allow an easy mechanization. This is an advantage if compared to sugarcane, which is propagated from stem cuttings (i.e. ratoons, in the range of 4,500–6,000 kg/ha). Furthermore, its production can be completely mechanized, although the easily fermentable sugars may generate some trouble in the post-harvesting period: processing operations need to be performed in a short period of time after harvesting to prevent sugar losses. Some solutions to solve this drawback are being studied: scheduling the harvest using varieties of different cycle length (short, medium and long cycle), concentrating the juice, improving ensilage conditions.

Another favourable characteristic of sweet sorghum is that it is an annual crop, and due to its short growth cycle (4 to 6 months) rotational cropping or double cropping systems are possible under certain climate conditions: in fact, in adequate tropical or sub-tropical conditions can be grown twice per year, increasing its profitability. Chosen properly, this feature could be positive for the agro-diversity, due to increase the period of soil coverage which reduces erosion and can preserve soil organic matter.

Sweet sorghum has different by-products that can be exploited with energy purposes. Some varieties produce also grains that can be converted into first generation bioethanol (there is starch in the grain). Bagasse (stem residues originated after juice extraction) can be used in two ways: they can be converted into second generation bioethanol or can be used to generate heat or electricity during the bioethanol process, the same that is currently done with sugarcane. Therefore, sweet sorghum could be used for first and second generation biofuel production at the same time. Leaves and also bagasse could be used as forage too.
To sum up, sweet sorghum has been chosen as interesting feedstock for bioethanol production mainly because of its high biomass yield, its high fermentable sugar content, its adaptability to a wide soil range and environments, its water requirements (lower than other irrigated crops as maize or sugarcane), its drought resistance, its well-known mechanization, and the easy valorisation of the bagasse, by-product that can be also used for energy purposes.

7.2 Botanical description

7.2.1 Systematic
Division: Magnoliophyta
Class: Liliopsida
Subclass: Commelinidae
Order: Cyperales
Family: Poaceae
Tribe: Andropogoneae
Subtribe: Sorghinae
Genus: Sorghum Moench
Species: Sorghum bicolor (L.) Moench
Subspecies: Sorghum bicolor subsp. bicolor
All sorghums identified botanically as Sorghum bicolor subsp. bicolor have 2n = 20 chromosomes.

Commercial varieties of Sorghum bicolor (L.) Moench are categorized into the following agronomic types: grain sorghum, fiber sorghum, forage (or fodder) sorghum, broomcorn and sweet sorghum. The agronomic orientation of the variety depends on its phenotypic characteristics.
Sorghum bicolor origin is supposed from rain-fed lands between Ethiopia and Sudan (Africa) and its domestication occurred probably around the years 4,000-3,000 BC. It was introduced in India (~ 1,500-1,000 BC), Middle East (~ 900-700 BC) and Far East (~ 400 BC). American introduction was more recent (~ 1850 AD).

7.2.2 Morphology
Sweet sorghum is an annual herbaceous species and, depending on the varieties, with a high ratoon capacity.

Stalks
Sorghum stems are usually solid like in sugarcane; this feature is an exception to the grass family. Stems are made up of a variable number of alternating nodes and internodes. The height ranges from 0.5 to 5.0 m and the width at the stalk base from 1.5 to 5.0 cm of diameter.
Regarding the cross-section structure, the stem consists of an external crown with numerous vascular bundles, densely arranged. Inside this crown there is a soft pith dominated by parenchyma tissue, where some scattered bundles appear. Most of the sugar, mainly sucrose, is accumulated in this pith.
One leaf arises from each node, which has a groove where the leaf grows. In this groove there is an axillary bud. All of the axillary buds are dormant except some of the lowest nodes of the stem, where tillers may grow from these axillary buds.

Either varietal characteristics or some cultivating conditions like plant arrangement and climate conditions (i.e. photoperiod and temperature) have a remarkable influence in sorghum tillering capacity.

**Leaves**

Sweet sorghum usually develops from 7 to 24 opposite-decussate leaves along the stem, depending on the variety, the latitude and the final degree of development that the stem could reach. There is usually one leaf per node.

Leaves are bright green, parallel-veined, have a long sheath that embraces the stalk and a leaf-blade whose length is 30 to 135 cm and width is 1.5 to 13.0 cm. Leaf-blade is flat, although in water stress conditions can longitudinally roll up, as it happens in maize. Stomata can be found on both sides of the leaf.

**Inflorescence**

Inflorescences are grouped in a panicle, which is usually apical. Its length is variable and when the inflorescence is well developed can reach 60 cm (peduncle included). The inflorescence consists of several branches that at the end support some pedicellate and sessile spikelets, which have two sterile florets being only fertile the upper one. Each floret has three stamens and a single ovary with two styles with feathery stigmas.

**Fruit**

It is caryopsis with a roughly rounded shape and differently coloured, depending on the variety. Sweet sorghum fruits are usually smaller than the grain sorghum ones. The weight of one thousand seeds is about 21g, varying between 16-28 g.

**Root system**

Root system is adventitious with fibrous and branched roots and can extend up to 1.5 m while the primary root, as same as other plants from the grass family, has early senescence and is substituted by roots originated in the underground part of the stem. Moreover, sweet sorghum develops brace roots at the lowermost nodes in a similar way of maize, that help to support the stem.
7.2.3 Biological characteristics

Development stage: spring-summer in temperate climates. Development cycle lasts about 4 months, from May to September, depending on location and variety. The maximum growing rate stage (elongation stage) must be coincident with the maximum solar radiation period. Sweet sorghum has a very quick development cycle.

Main phenological stages: emergence, tillering, elongation, panicle emergence, flowering, maturity. If it is sown in spring, when temperature is mid, generally will emerge in 7-10 days. The duration from emergence to tillering is about 30-40 days, and from emergence to elongation, 47-55 days. Elongation stage depends on the variety and corresponds to 30-90 days. Flowering usually happens 5-7 days after panicle emergence. Maturity stage is also very variable, depending on the variety, but the common period is 30 days.

Sugar accumulation: there is a correlation between maturity degree and sugar content in sorghum stems. Variety choice, sowing date and growing conditions are the main factors to optimize sugar accumulation. Maximum accumulation happens after panicle appearing, especially after flowering. In areas where the temperature in September is low, the development of sorghum is early interrupted and sugar accumulation is stopped. Sugars stored in stalks are glucose, fructose and mainly sucrose. The more mature is sorghum, the higher the sucrose content and the lower the glucose and fructose content.

7.3 Technologies in cultivation and harvesting\textsuperscript{42,43,44,45,46,47,48}

Sweet sorghum is tolerant to drought and different soil conditions; varieties exhibit different response to photoperiod; there is a wide range of genotype diversification that allows adaptation for different growth lengths. Because of that, sweet sorghum can grow in a wide range of agricultural environments.

7.3.1 Soil preparation

Adequate seedbed preparation is needed to facilitate the emergence of plantlets and to remove weeds. Soil must be ploughed and finely harrowed for sowing. Compaction should be prevented.

It is also recommended to apply an herbicide (e.g. Glyphosate) to control weeds. Soil preparation shall be made taking into account the irrigation system that will be available for the crop. Sorghum has a good response to furrow irrigation, which prevents lodging; in this case ridges would have to be made at the step of soil preparation. In case of sprinkler or drip irrigation, land surface is levelled or maintained flat.
7.3.2 Fertilization
The dose of fertilisation depends on soil fertility and wanted productivity. In Mediterranean climates, where soil fertility ranges from low to moderate, the fertilisation needs are about: 100-150 kg N, 60-100 kg P₂O₅ and 60-100 kg K₂O per hectare. It is recommended a nitrogen application done in two times: before sowing and 20-30 days after the emergence.

7.3.3 Sowing
Temperatures should be higher than 10-12 ºC for sorghum germination and there must not be any frost risk. Preferable soil moisture is the field capacity. Taking into account the cycle length and the fact that the stage of sugar accumulation is affected by low temperatures, in the Mediterranean climates sowing should be performed at the beginning of May so that sorghum can be able to complete its cycle. Sowing is usually performed in rows 0.75 m apart with a distance of 0.10-0.15 m in the row; ≥5 cm depth should be kept. The dose of sowing depends on the variety and seeds germination capacity; the specific weight usually ranges from 30 to 70 seeds/g. A germination test prior to sowing is recommended. After sowing it is essential to maintain good soil moisture conditions to ensure the emergence.

The election of the variety is extremely important to obtain good crop yields. Long cycle varieties are usually more productive than the short cycle ones. However, in some locations long cycle varieties are not advisable because temperatures should be warm during the whole cycle to express its potential. In Mediterranean climates this condition means that the temperature must be mild or warm in September.

- Short cycle varieties: cycle length of this type of varieties is about 70 to 90 days from emergence to flowering in Mediterranean climates. For instance, the varieties named Mer 60-2, Mer 78-13, Soave, Atlas, Madhura.
- Long cycle varieties: they may need about 110 days from emergence to flowering. For instance, the varieties named Keller, Dale, Wray.
7.3.4 Irrigation

Like for any other irrigated crop, the irrigation requirements of sweet sorghum depend on the site (i.e. water balance is affected by the temperature and rainfall regimes of the site) and the irrigation system used for the crop. Besides, there is the intrinsic factor of the variety requirements. Generally they may range between 500 and 1,000 mm.

For several varieties of sweet sorghum and within a compatible water availability range, the water use efficiency of the crop decreases at higher water regimes. Values of 3.7-6.1 kg db/m³ evapotranspired water have been reported for the water use efficiency of Keller variety grown in the centre of Spain.

Sweet sorghum can grow in conditions of some water stress but yields are affected. In Mediterranean conditions, where water shortage is a fact during summer, a compromise between irrigation dose and expected yield should be reached.

7.3.5 Crop protection

Since the earliest stages of the crop, namely from sowing to canopy closure (i.e. approximately when the crop is 1m high), sorghum is very sensitive to weed competition. Consequently land must be carefully prepared before sowing with the objective of eliminating weeds. It is also useful to apply a herbicide before land preparation. Anyway, herbicide must be always applied in pre-emergence, immediately after sowing, because sorghum germination is very fast and the crop could be affected if the herbicide is applied late.

Pests and diseases are similar to corn and sugarcane in those areas where both are extensively cultivated, like in the South of the US. In places where those crops are not spread, no problems should arise. For instance, no pests or diseases have been observed in experiences carried out in central Spain, occasionally the presence of borer.

The main abiotic damages that sweet sorghum could suffer are cold and lodging.

1. Cold. Adequate selection of varieties (cycle length) and sowing date are necessary to prevent cold damages.

2. Lodging. Adequate selection of varieties (plant height, stalk diameter, canopy density) is essential as well as the nitrogen fertilisation rate and harvesting date.
3. Setting. In places where damages by wind are possible, shorter varieties with low lodging tendency and low nitrogen rates are recommended. In addition, in order to avoid wind risks during autumn season it is better to harvest as soon as possible.

7.3.6 Harvest
Harvest should be undertaken when biomass and sugar accumulation reaches its peak. The optimum harvest time is usually after panicle development since the highest sugar concentration happens after flowering. Obviously the date depends on the variety and the climate conditions. Whenever possible, frequent determination of sugar concentration in the stems is recommended after flowering, at least the first year of the variety growing, in order to determine its performance.

Sweet sorghum harvest is finalised to the recovery of all sugars which are concentrated most of all in the stalks. Therefore the way in which harvest is performed is by cutting the stems at their base; for bioethanol purposes, sorghum leaves are rejected.

There are a number of studies about the mechanization of sweet sorghum harvest. Some of the machinery used are: sugarcane combines, harvesters that cut and bale the stems, forage choppers and some prototypes. In the US, forage corn harvesters are recommended but the produced crop must be immediately delivered to the bioethanol plant for its processing. This is a convenient method because conventional machinery is used and thus, operation costs are cheaper. The main drawback is the high risk of sugar losses (juice loss and sucrose instability).

7.3.7 Post-Harvesting
In spite of the fact that sweet sorghum is an interesting crop for bioethanol even in temperate climates, little progress has been made on the penetration of this crop. This happens, most of all, because the period of time comprised between harvesting and the processing phase is too short. Moisture content at harvest is very high (70-80%) and temperatures at harvest time are mild. Subsequently to mowing or chopping, juice losses happen. Moreover, sugar degradation (unwanted fermentations) is fast triggered because high biomass moisture is jointed to a high concentra-
tion in easily fermentable sugars. To prevent fermentations sweet sorghum must be harvested quickly and the produced crop must be immediately processed in the plant. In temperate climates (e.g. Mediterranean climates) the harvesting period is reduced by the fact that if the harvest is delayed the climate conditions become bad for this crop and damages by lodging, cold or sugar losses may happen. In other words, the problem is the impact of the high seasonality of this crop in the production and in the industrial process.

To prevent the above mentioned problems several measures have been suggested. One is to grow varieties of different cycle length (short to long cycle varieties) or to combine several sugar crops which help to make longer the harvesting and processing period. Another measure is to extract and preserve the stalk juice or sugars from fermentation. Additionally, it is recommended to use bagasse for further processing as feedstock for bioethanol production.

7.4 Breeding programs

Sweet sorghum has been studied as an alternative crop for sugars/ethanol in temperate regions since the end of the nineteenth century. Breeding programs aim at the production of crystallized sugars and syrup, the improvement of the carbohydrate yields and also the prevention of leaf anthracnose and stalk red rot. Several attributes of sweet sorghum as juice extraction percentage, degree Brix value, non-reducing sugars, total sugars and inversion enzyme activity are being studied nowadays. Presently sweet sorghum breeding activities are being carried out in the European SWEETFUEL project, supported by the EC (7th FP).

7.4.1 Breeding for temperature environments

Temperature is associated to the emerging and flowering period and it is also related to stalk production and sugar content. Sweet sorghum grows with high radiation and it is adapted to southern European climates but its growth is limited in North and Central Europe because of low temperatures, which affect the biomass yield. The main objective of this project is sweet sorghum adaptation to low temperatures. Biomass yield, tolerance to cold, fast and homogeneous germination, and disease resistance are pursued. Breeding and varietal testing is being carried out in European countries involved in the SWEETFUEL project: Germany, Italy and France.

7.4.2 Breeding for drought prone environments

One of the main limiting factors for this crop is its water requirements, in spite of the fact that they are lower than sugarcane ones. Sweet sorghum may have a double purpose: grain and sugars, with a good drought adaptation, juicy stalks with sugar content and good digestibility. The breeding program objectives, also in the
SWEETFUEL project, are the improvement of the juice in the stems, avoiding drought effects even if increasing sugar content. These activities are being carried out in India, Mexico and South Africa.

7.4.3 Breeding for low fertility soil environments
Sorghum is a suitable crop for areas located in semi-arid to semi-humid climate regions of subtropical and tropical latitudes, as moist savannas. Soil acidity and aluminium toxicity are important existing constraints in these areas. Breeding programs are mainly lead to improve genetic tolerance to these restrictions that could allow to obtain higher biomass yields and higher stalks juice and sugar content. These objectives are also included in the SWEETFUEL project; experiences are being performed in countries such as Brazil or South Africa.

7.5 EU experiences on sweet sorghum cultivation
7.5.1 Italy\(^{59,60,61,62,63,64,65,66,67,68,69,70}\)
Although in March 2011 the Italian law has acknowledged the Directives 2009/28/CE and 2009/29/EC (legislative decree 2011/28), the national bioethanol production did not increase in the last year. The only existing plants are producing bioethanol using exhausted marcs and grapes from the distilleries of the wine industry or residues of the fruit juice production. Their capacities are still very small and consequently the national demand of bioethanol is covered mainly with the importations, in order of importance from Pakistan, Turkey and Brazil.

As regards with bioethanol crops, in Italy there is a long tradition in the agricultural researches about sorghum as alcoholic crop since the early 1930’s due to the autarkic policies of that time. The knowledge of the crop and availability of the sweet sorghum varieties have had a development thanks to the studies and researches aimed to the genetic improvement. In fact, in absence of a world trade the natural hybridization made in the late 1930’s and afterwards the breeding between the superior lines followed by the selection of segregating generations have been the only systems to obtain in Italy the sweet sorghum varieties.

Since the end of 1980’s further studies and field trials with this crop have been done by A.Biotec. Starting from the fact that the commercial varieties, selected mainly in the US in very different conditions respect to those of Italy showed a not perfect adaptability, the researches were focused on the genetic improvement of these species with the objective of developing hybrids with high sugar content, suitable for pedoclimatic areas of the central and northern regions of Italy. The varietals trials carried out during all the 1990’s allowed to obtain a high number of hybrids with high sugar content, and other with high yield in grain or fiber. One of the hybrid breeding (e.g. LP 34 M x LP 113) has shown of being very superior if compared to the better sugar varieties used as test, with a yield of 44 t/ha of dry matter. Pluriennial trials made by A.Biotec in different areas in the North Italy shown that some varieties (e.g. Wray, Dale, Keller, Mn 1500, M 81-E, Theis and Rio) gave production of stems between 55 and 70 t/ha wb and productions of fermentable sugars of 6-8 t/ha. The better varieties were the later because they had the capacity of exploiting a longer vegetative period. Nevertheless these varieties cultivated in the environments of southern regions of Italy, shown an instability of the production caused by a high sensibility for
the low temperatures of Italian spring, a high predisposition to the lodging and a high tardiness that sometimes did not allow the harvesting.

Since the 1990’s, ETA-Renewable Energy has coordinated some studies to apply sweet sorghum in the feed and energy chains under the typical Mediterranean climate of South Italy (i.e. Metaponto, Matera). In the framework of the ECHI-T project supported by the EC (i.e. 5thFP) the integrated production of electricity, bioethanol and pellets for animal feeds from sweet sorghum has been investigated at level of pre-feasibility study. Concerning the agricultural aspects, the relationship between water use, light interception and dry matter production were analysed in an environment characterised by clay and deep soil, high temperatures and elevated evaporative demand of the atmosphere. Sweet sorghum provided high values of WUE and RUE (4.8 kg/mm and 3.3 g/MJ, respectively) and the comparison between these parameters allowed to evaluate the crop capacity to utilise the water and energetic resources of the environment. The research showed, besides, that high irrigation regimes are necessary in this type of environment to obtain a satisfactory productive level. Furthermore during the same trials the salinity tolerance of sweet sorghum has been confirmed. In hilly environment or unfavourable ones in relation to the water availability, choosing precocious hybrids with short crop cycle resulted preferable. The most favourable period for cultivation in South Italy is half April-beginning of May, with the harvesting at half August-half September. The obtained crop yields are 35-40 t/ha with good water support and 20-25 t/ha with low water support.

Since the same period sweet sorghum has been also studied in Italy by other important research groups, such as the University of Catania, the University of Bologna and ENEA. These studies have been carried out through international and national collaborations like “Sweet Sorghum Network - JOUB 0036”, “Sweet sorghum, a sustainable crop for energy production in Europe: agricultural, industrial improvement, optimisation and implementation - AIR CT92 0041”, “Environmental studies on sweet and fiber sorghum, sustainable crops for biomass and energy - FAIR CT96 1913” and “Innovative sustainable techniques for the production and transformation of energy crops and non-food - TISEN”. These researches have been focused on the response of sweet sorghum to environmental factors and to crop husbandry; moreover, different nutritional studies with particular focus on nitrogen and crop efficiency in the use of water resources, have been carried out too.

In the last years the results of these researches have been applied mainly for the production of animal feed (i.e. forage and grain varieties) and more recently also for the production of biogas through the anaerobic digestion with other organic substrates (e.g. manure).

As regards with the application in the biogas production, the studies of Crpa S.p.A. have evidenced that sorghum growth benefits from the fertirrigation with manure and digested matter (i.e. residue of the anaerobic digestion), allowing an integrated management of the chain and of its by-products.

In order to improve the application of sorghum in bioenergy sector, some researches carried out by CRA-CIN have been aimed to assess the differences between varieties of fiber sorghum and sweet sorghum in terms of biomass and sugar yields. The results obtained in fields in Marche and Emilia-Romagna regions (central Italy) have suggested that in these climate conditions the differences are not very high and then
some of the considered varieties (i.e. H133, Bulldozer, Padana 1) have a dual purpose. The mechanisation of the agricultural operations for sorghum varieties has been studied for a long time by CRA-ING. In the contest of the research activities some prototypes have been designed and tested for the harvesting and for the conditioning of biomass. Especially one prototype for fiber sorghum has been designed and recently the pre-commercial version is being used in experimental fields in Italy by Mossi & Ghisolfi Group and Coprob.

The application of sorghum in bioethanol chain is being especially studied by some research groups, such as Mossi & Ghisolfi Group (Chemtex Italia S.p.A.), the Universities of Bologna and Turin, CETA, ENEA and CRA-RPS.

The researches of Chemtex Italia S.p.A. have been carried out in Emilia-Romagna in cooperation with the Regional Administration, the Province of Parma, the University of Parma and the University of Sacro Cuore. Different fiber and forage sorghum varieties have been compared in order to assess their yields and to study the logistics for the supplying of a processing plant to produce 2nd generation bioethanol. The results have confirmed satisfactory yields of the considered sorghum varieties with low input (chemicals -50% DPI, without irrigation): 20-25 t/ha db. Furthermore the possibility to introduce sorghum in the cropping systems of farms in rotation with autumn-winter crops has been verified.

Recently the University of Bologna are participating in the project SWEETFUEL, supported by the 7th FP. In Italy the research activities are aimed to select hybrids characterised by a high resistance to low temperature in order to anticipate the sowing, to dilate the cultivation period and to optimize the supplying of the processing plants. In particular the opportunity to develop short chain to supply decentralised plants and to produce bioethanol and other energy commodities using sweet sorghum has been investigated since 2007 in different areas of Italy.

In Piedmont region different experimental trials like cultivating sweet sorghum for bioethanol production purpose, complementing it with the evaluation of ensiling strategy for the sugar preservation, have been carried out by CETA in collaboration with the Agrarian Faculty of the University of Turin in 2007-2008 with different field trials in North Italy.

The MULTISORGO project, supported by the MIPAAF and implemented by CETA in cooperation with ENEA and CRA-RPS, is aimed to test some commercial varieties of sweet sorghum in the South and North Italy climates conditions (Basilicata and Friuli Venezia Giulia regions, respectively) and to express the whole energetic potentialities of the crop, assessing the production of 2nd generation bioethanol from bagasse and the anaerobic digestion using residual vinasse. The field trials confirm that in the Mediterranean climate the irrigation is necessary to ensure the economic viability of the cultivation (i.e. 2.4-4.6 t/ha db without irrigation versus 7.6-11.3 t/ha db with irrigation in 2010) and that in the temperate oceanic climate the rainfall (e.g. 670 mm in the period May-Sept 2010) is sufficient to reach satisfactory yields (i.e. 14.3-19.0 t/ha db in 2010 and 16.3-21.1 t/ha db in 2011).

7.5.2 Greece

In Greece, as in most European countries, bioethanol was introduced in the market with the Directive 2003/30/EC, and special attention to it has recently been given in the RED. At the moment the bioethanol production is nonexistent. Already the use of bioethanol
as an alternative fuel to petrol or a complement thereof can be encountered.

Among the important energy crops there are varieties of sorghum for bioethanol production because of its high fermentable sugars content and combustible organic substances, tolerance to water stress and low nutrient requirements. For the production of biomass and bioethanol, sweet sorghum holds a prominent position because of the high photosynthetic capacity due to the C₄ photosynthetic metabolism.

The EC has funded in recent years several research studies on sweet sorghum (programs such as AIR, FAIR, etc.), carried out by Greek research centres, because this crop is considered as an alternative and economically viable energy crop.

CRES in cooperation with the Agricultural University of Athens and the University of Patras, through the participation in national and European research projects, has cultivated experimental fields in many parts of Greece.

The results of these experiments are identical to the average values of yields under full irrigation and fertilisation in Mediterranean environments.

Dalianis et al. have studied the effect of plants density on the growth and on the yield of sweet sorghum Keller varieties. The plants were sown in rows with a distance of 0.7 m and the distances of the plants on the line were 5, 10, 15 and 20 cm. They found that the density of 71,000 plants/ha (i.e. distance of 20 cm) gave the best yields in fresh and dry biomass (about 113 t/ha wb). This density had also the largest number of leaves and the greater height of plants.

Also Dalianis et al. as part of research team of CRES studied in the early 1900’s the adaptability of varieties of sweet sorghum in several regions of the country and the influence of different levels of irrigation and nitrogen fertilisation on yields of fresh biomass, on sugar content in the stalks and the agronomic characteristics of different varieties of sweet sorghum. Sweet sorghum is well adapted throughout Greece and can be grown from southern to northern regions and from sea level to high altitudes (i.e. up to 800 meters). It can be cultivated in various soil types ranging from marginal to very fertile ones. The lowest values for biomass and sugar production were registered in marginal, abandoned and poor soils (in term of organic matter content), whereas the highest yields corresponded to fertile fields located in southern Greece.

Moreover, it was found that Keller variety evidenced the most efficient yields in terms of fresh biomass and sugars: the produced fresh biomass was in the range of 87 to 144 t/ha wb and the obtained sugars were in the range of 9 to 12 t/ha.

Irrigation seems to affect the agronomic characteristics of the cultivation and the yields of biomass and sugars. In contrast, the nitrogen fertilisation does not seem to affect the yields of fresh biomass and sugar content. Consequently the application of reduced nitrogen rates is justified. The team also studied the effects of abiotic factors on crop physiological parameters such as evapotranspiration, water use and solar radiation. Yields ranged from 10 to 12 tons fresh biomass/ha. The radiation use efficiency, RUE is 3.5 g db/MJ and the water use efficiency, WUE is 55 kg/mm of water.

In more recent experiments in the late 1900’s, research group of CRES studied the agronomic characteristics and performance as well as the effect of different levels of irrigation and nitrogen fertilization in a number of varieties (Sofra, Korral, Colley, Keller, Mn 1500) and sweet sorghum hybrids. They confirmed that the most profitable varieties were Keller and MN 1500. The yields of these varieties ranged from...
105 to 115 t/ha wb with a density of 110,000 plants/ha. In these experiments they found effects of fertilization on agronomic characteristics of plants such as height and green leaf area index (6.2 versus 4.4 in the fertilization of the soil).

Dercas et al.\textsuperscript{78} in experimental fields of Vagias Viotia Kopaida located in central Greece, in 1993 and 1994 performed cultivation tests in the ambit of the European program AIR, with four levels of irrigation (i.e. IH, IM = 1/2 IH, IL = 1/4 IH and IHA = IH until flowering) and two levels of nitrogen fertilisation (i.e. NL = 40 kg N/ha and NH = 120 kg N/ha). In the experimental fields of Vagias harvested in 1993, yield was 12.2 kg/mm with no differences in performance between the levels of irrigation. In 1994 yields varied from 7.45 kg/mm in the high irrigation level (IH) to 11 kg/mm in the low irrigation level (IL). This difference was attributed by researchers to the fact that there was no underground water in the experimental field of Kopaida. The dry biomass was calculated at 3.2 kg/mm for the high irrigation level for both years of experiments. Fertilisation levels had no effect on the performance of either the fresh or dry biomass in both years. This was attributed to the high fertilisation of the field that had been applied in previous years and low requirements of nutrients of the cultivation.

\textbf{7.5.3 Spain}\textsuperscript{79,80,81}

Sweet sorghum as energy crop has been studied in Spain since the decade of 1980’s. The research teams leaded by Centre for agricultural research & development of Málaga and Polytechnic University of Madrid have contributed substantially to the knowledge of this crop.

Significant R&D projects on sweet sorghum carried out in Spain (totally or partially) are the following:


- 2010-2011. “Initiative for the development of the cultivation of sweet sorghum with bioenergy purposes – SORGOSWEET”, Ministry of the science and innovation, project PlanE.
Table 21: results of the cultivation of commercial short cycle varieties. KEY: Height: very tall (VT), tall (T), medium (M), short (S); Lodging resistance: poor (*), intermediate (**), good (***) ; Development cycle: Early (E), intermediate (I), late (L); Panicle type: Open (O), semi-compact (SC), compact (C); Grain: yes (Y), no (N); Biomass yield: very high (VH), high (H), medium (M), low (L); Sucrose content: poor (*), intermediate (**), good (***) . The slash refers first harvest (15th September, 85 DAS) and normal harvest (18th October, 118 DAS).

**Figure 14:** phenological state as a function of sorghum variety in trials carried out in Madrid, Spain. Sowing date: 22nd June 2010; harvest date: 15th September 2010 (source: Agro-Energy Group of the Polytechnic university of Spain)
A number of experiments on sweet sorghum cultivars from latitude 36º to 41ºN in Spain have shown that in non-limiting water conditions, varieties and yields are highly influenced by the latitudinal gradient and climate conditions. Late varieties are suitable for southern areas provided with irrigation while early varieties are more suitable for Mediterranean-continental areas. It has been seen that variety selection is a key factor for growing sweet sorghum.

A recent research line is the use of sorghum as a second crop in Mediterranean environment. For that purpose, a key issue is the choice of a suitable variety. The assessment of commercial varieties of sorghum as short cycle crops for biomass and sugars production in one-year experiment by the Agro- Energy Group of the Polytechnic University of Madrid is presented in Table 21.

**Topic: Bioethanol and bio-ETBE**

Bioethanol is ethylic alcohol used as transportation fuel and derived from the alcoholic fermentation of free sugars, such as glucose, sucrose, fructose, or hydrolysed polysaccharides, such as starch, cellulose, hemicellulose, fructans (i.e. inulin).

Basing on its own characteristics bioethanol is suitable to feed the Otto engines instead of petrol:

- the LHV is high: 27 MJ/kg
- the MON and RON values allow an effective combustion control during the compression in the piston: MON 96, RON 130, octane number (i.e. average between MON and RON) 113.

Alternatively bioethanol can be converted in bio-ETBE, which is an antiknock compound usable in the Otto engines instead of MTBE:

- the LHV is high: 35 MJ/kg
- the MON and RON values indicate a good behaviour as antiknock compound: MON 102, RON 118, octane number (i.e. average between MON and RON) 110.

Bioethanol contributes to reduce the GHGs emissions from the transport sector, because it derives from biomass, not from fossil sources; consequently the balance between carbon sink and emission is like zero.

Bio-ETBE is considered GHGs neutral only for the fraction of the molecules deriving from biomass: 47% w/w.

The main raw materials converted in bioethanol are:

- sugar matter: sugarcane, sugar beet, sweet sorghum, molasses, marc
- starch matter: grain of cereals, potato, sweet potato, cassava
- lignocellulosic matter: giant reed, straw, maize stalks, organic fraction of the MSW.

Basing on the converted raw materials and then on the complexity of the implemented technology, bioethanol is considered a 1st generation biofuel, a 2nd generation biofuel or a 3rd generation biofuel:

- 1st generation: converting sugar and starch matters
- 2nd generation: converting lignocellulosic crops (e.g. giant reed)
- 3rd generation: converting lignocellulosic residues (e.g. straw, MSW).
8. GUIDELINES FOR THE EU MODEL TO PROCESS SWEET SORGHUM AS ENERGY CROP

8.1 Introduction
Sorghum is a multipurpose crop because it supplies high yields in biomass, sugar and grain depending on the chosen varieties.
At the current time the sweet sorghum varieties provide mainly biomass and sugar, whereas its potentiality as grain crop is not yet expressed. Many agricultural researches are aimed to overcome this limit, selecting hybrids with high yields in biomass, sugar and grain at the same time. Actually, in order to express all the potentialities of the crop, other agricultural researches are directed to optimize the harvesting operations, separating all the products: biomass and sugar on one side, grain on the other side.
Since these researches are not yet finished, the model to process sweet sorghum foresees the exploitation of sugars and lignocellulosic biomass.

![Diagram of the plant to process sweet sorghum in bioethanol and energy commodities](image)

In accordance with the scheme in Figure 15, the sweet sorghum biomass is crushed and sugar juice is processed in bioethanol.
Bagasse, which is the lignocellulosic residue of the crushing unit, is dried and burnt in CHP plant to get electricity and heat.
Vinasse, which is the residue of the distillation and rectification unit, is a feedstock for the anaerobic digestion, to use in co-digestion eventually with other substrates like for example manure as microbial inoculum. The obtained biogas is purified and burnt in CHP plant to get electricity and heat.
This approach for processing sweet sorghum allows different variations that can be applied in the planning of a specific chain model to supply decentralised small-medium plants in the EU.
In fact, the conversion of the sugar juice in bioethanol and the energetic exploitation of bagasse and vinasse can be the sole production line or can be one of the production lines implemented in the plant. These different strategies are explained in detail in the specific chapters. In particular, the use of sweet sorghum as sole feedstock is deepened in three case studies (i.e. in Italy, in Greece and in Spain) and the feasibility for processing sweet sorghum plus another raw material (i.e. sugar beet) in the same plant is reported in the Spanish conditions.

All these applications have some common elements regarding the dimensioning of the chain supply, the technological contents of the processing and the by-products exploitation. Consequently, the following paragraphs are aimed to give the main guidelines, which are common to the different applications. They are the indicative input data to perform a feasibility study and at this aim they require a contextualisation to each specific situation.

8.2 Dimensioning of the chain supplying

In the creation of the EU model the capacity as anhydrous bioethanol obtained from the processing of sweet sorghum is assumed as criterion for the dimensioning of the chain supplying.

As appropriate this dimensioning regards the whole plant (if sweet sorghum is the sole feedstock) or the specific production line to obtain 1st generation bioethanol from this crop (if the plant processes different raw materials).

Two elements are required in the assessment: the agricultural surface cultivated with sweet sorghum and the range of supplying.

Agricultural land requirement

The required agricultural land depends on the yields of biomass and sugars, which are consequent for example of the kind of soil, the water availability, the climate, the grown variety.

The main specificities have been traced to some reference scenarios, in order to give an indicative value to the stakeholders (Table 22).

The reported ranges for the yields concern some different sweet sorghum varieties, currently available in the EU market.

Two different types of environment are analysed and in each one the conditions to ensure the economic viability are considered.

The cultivation of sweet sorghum in marginal lands is taken into consideration for contexts where the economic viability is guaranteed and the related yields correspond to the lowest values in the reported range for each type of environment.

Especially in the Mediterranean environments (i.e. South Italy, Spain, Greece) the cultivation of sweet sorghum without irrigation is excluded because the biomass yields are too low. In the temperate environments (i.e. North Italy) only the eventual emergency irrigation is considered because the rainfall during the growing period is usually sufficient (e.g. 670 mm in May-Sept 2010).

These data are the input to calculate the hectares which must be cultivated with sweet sorghum in order to supply the plant, basing on its capacity. Nevertheless, for
each specific situation the calculated surface could require a wider area, for example if rotations with other crops are proposed in the considered region in order to protect the soil fertility.

These values of macro scenario, of course, require a following careful contextualisation to calculate the actual dimensioning of the chain supply.

**Range of supplying**

Concerning the distance between the plant and the fields, different evaluations have to be integrated. The main elements are the impact of the transport on the energy balance of the chain, the respect of specific limits to access to eventual national aids (e.g. short chain recognised for a maximum range of supplying), the logistics consistent with the requirements of the farms (e.g. the necessary number of agricultural machinery, number of driven kilometres) and the plants (e.g. timing of supplying during the harvesting) and with the impact of the consequent traffic in the considered area.

In order to give some indications for the range of supplying and its repercussions, in the Table 23 the details for two simulations are reported.

### Macro scenarios to plan the chain supply

<table>
<thead>
<tr>
<th>Type of environment</th>
<th>Agricultural yield</th>
</tr>
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<tbody>
<tr>
<td><strong>Type MEDITERRANEAN</strong></td>
<td></td>
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<tr>
<td>Low fertility soils</td>
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<tr>
<td>Dry climate</td>
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<tr>
<td>Irrigation</td>
<td>Biomass yield 10.3-35.0 t/ha db</td>
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<tr>
<td></td>
<td>Bioethanol yield 1.5-6.0 t/ha 1.9-7.6 m³/ha 40.5-162.0 GJ/ha</td>
</tr>
<tr>
<td><strong>Type TEMPERATE</strong></td>
<td></td>
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<tr>
<td>Medium fertility soils</td>
<td></td>
</tr>
<tr>
<td>Temperate oceanic climate</td>
<td></td>
</tr>
<tr>
<td>No irrigation</td>
<td>Biomass yield 14.3-19.0 t/ha db</td>
</tr>
<tr>
<td></td>
<td>Bioethanol yield 2.1-3.4 t/ha 2.8-4.4 m³/ha 56.7-91.8 GJ/ha</td>
</tr>
<tr>
<td>Irrigation (emergency)</td>
<td>Biomass yield 30.0-40.0 t/ha db</td>
</tr>
<tr>
<td></td>
<td>Bioethanol yield 4.3-6.1 t/ha 5.9-7.9 m³/ha 116.1-164.7 GJ/ha</td>
</tr>
</tbody>
</table>

Table 22: yields in biomass and bioethanol obtainable from sweet sorghum in some reference type of environments^83,84^. 3,700-3,800 hectares cultivated with sweet sorghum

<table>
<thead>
<tr>
<th>3,700-3,800 hectares cultivated with sweet sorghum</th>
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<tbody>
<tr>
<td>Maximum range</td>
</tr>
<tr>
<td>15 km 51</td>
</tr>
<tr>
<td>20 km 52</td>
</tr>
</tbody>
</table>

Table 23: results of two simulations for the supplying of a plant with capacity 10,000 t/y as anhydrous bioethanol^85,86^.
In the model creation the dimensioning of the units for the by-products exploitation is based on the amounts of obtained bagasse and vinasse, which are linked to the cultivated agricultural land and then to the assumed capacity as anhydrous bioethanol. The main elements to dimension the related units are reported in the specific paragraph (7.4 Exploitation of by-products).

Figure 16: harvesting yard

**TOPIC: PRODUCTION OF BIOETHANOL**

The bioethanol production is based on the alcoholic fermentation carried out by microorganisms in controlled conditions. The correspondent chemical reaction is described as follows:

\[ \text{C}_6\text{H}_{12}\text{O}_6 + \text{H}_2\text{O} \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2 + \text{H}_2\text{O} \]

Although the fermentation is the core of the production, the complete processing depends on the kind of raw material: free sugars are directly fermentable, whereas polysaccharides require a previous hydrolysis. Furthermore the complexity of the hydrolytic step depends on the kind of polysaccharides: free sugars can be easily obtained from starch, whereas cellulose and hemicellulose are structural carbohydrates, strongly tied to lignin, and then their hydrolysis is more difficult.

The kinds of processing are briefly summarised in:

- **sugar matter:**
  1. extraction of free sugars from biomass
  2. fermentation
  3. distillation and rectification
  4. dehydration

At the end of the processing 1st generation anhydrous bioethanol is produced.

- **starch matter:**
  1. enzymatic hydrolysis: liquefaction with alpha-amylase and saccharification with gluco-amylase
  2. fermentation
  3. distillation and rectification
8.3 Processing of the sweet sorghum biomass to bioethanol

The technological sections for the production line of 1st generation bioethanol are: the sugar extraction unit, the concentration unit for the storage of the sugar juice, the fermentation unit, the distillation and rectification units and finally the dehydration unit.

8.3.1 Sugar extraction unit

The extraction of free sugars from the chopped biomass can be carried out through direct pressing using the rolling mills or through a lixiviation system.

In both processes the extraction is carried out using hot water (75-85 °C) in the ratio between feedstock and hot water of 1:0.1-1:1. The extraction yield is in the range of 93-98%, considering a range of 85-93% of extraction yield using a rolling mills series (from 3 to 5 rolling mills) and a range of 93-98% of extraction yield using a continuous diffuser.

In case of crushing into horizontal or vertical power mills, the working principle is the application of high pressure, which is exercised by some couples of rollers (TRPF milling system): 3 couples in the small vertical crushers, up to 9 couples in the big horizontal ones. The speed of the top roller is usually 10-12 rpm in small mills, 6-8 rpm in large mills. In order to improve the extraction efficiency, the optimal addition of hot water is 10% w/w.

The working scheme of the crushing unit is reported in the following figure.

Alternatively, the operation of the diffuser is based on systematic counter that puts the raw material under current washing by means of imbition water. In practice, this is achieved by forming a bed of shredded stalk or first mill bagasse on a conveyor. Water is added at the discharge end of the conveyor and percolates through the bed of bagasse and the perforated...
sleta of the conveyor. The water dissolves the sugar in the bagasse and the thin juice thus formed is collected in a hopper. This juice is moved forward one stage by pumping and the process is repeated until the juice reaches maximum concentration at the feed end of the diffuser. The diffuser may be conditioned either for single-flow or for parallel-flows juice circulation.

![Figure 18: continuous extraction](image1)  
![Figure 19: continuous diffusion diagram](image2)

Usually the diffusers are designed from 35 m to 52 m long; the cross section is rectangular and diffusers of different capacities are made in different widths. The conveyor grids and screens are supported by 2 outboard type roller chains with a pitch of about 3 feet. These chains are supported at the extreme ends by sprockets. At the driven end, the sprockets are coupled through a gearwheel and pinion to a variable speed hydraulic drive or electric gear-motor drive.

The conveyor itself is made of articulated frames to which the screens are fixed. The screens and frames are rigidly attached to corresponding links of the 2 chains. These chains are fitted with self-lubricating bushings. The rollers ride on parallel rails. The return rails are completely exposed underneath the housing, giving full visibility and accessibility to the screens. The thickness of the bed varies from 1.5 m to 2 m. The space between the 2 conveyor spans is occupied by a large tank with a sloping bottom split into individual hoppers by means of vertical plates. These vertical plates have horizontal slots, at specified levels, through which the juice overflows to the next hopper. At the end of the conveyor, there is a revolving scraper to even out the flow of bagasse which

![Figure 20: continuous diffuser](image3)
falls in an outlet hopper. This hopper is provided with a conveyor for removing the bagasse. The diffuser is equipped with lifting screws in the press-water feedback area.

During the whole duration of its passage through the diffuser, the bed of stalks is submitted to intensive sprays of juice of progressively decreasing concentration. The juice is evenly sprayed above the bed by a series of overflowing troughs extending on the whole width of the housing. One of these troughs is fitted above each juice-collecting hopper and designed to distribute uniformly the juice across the bed, with an accuracy of 2%. The curve showing the decreasing concentration of the juice in the successive hoppers that is very steady.

The last trough is fed with pure water. All the juice hoppers have the same width. They collect the juice percolating from each juice distributor through the bed of stalks. Each hopper is piped to an individual high capacity centrifugal pump. Each pump is piped to take juice from one hopper and to spray it above the preceding hopper (in opposite direction to the movement of the bed). A last single pump feeds the richest juice to the rich juice tank. Another pump of great capacity continuously circulates
rich juice on the fresh prepared stalks of sweet sorghum. The intensive flow of stalks or first mill bagasse is fed into the diffuser by a drag type cross conveyor so designed as to spread the feed evenly on the diffuser conveyor. Juice from the rich juice tank is pumped to the factory. The diffuser is operated and controlled from a central panel on which all instruments are grouped. The main advantages of the continuous diffusion are:

- high extraction achieved in combination with existing milling equipment or in completely new extraction plants;
- low initial cost of the overall extraction plant because diffusers are designed to work with conventional sweet sorghum stalks preparation and milling equipment. The diffusers can be installed outdoors;
- low maintenance costs because of massive design and extremely slow movement of the main conveyor;
- low operational costs: diffusers are completely automated and can be operated by 1 man per shift. Lubrication costs are negligible;
- low power requirements: live steam is not needed. Steam of low-pressure is used for juice heating in the diffuser. All moving parts are driven by electric motors;
- very wide capacity range: diffusers can operate without modifications and without loss of efficiency from 30% to 10% over nominal capacity. By varying the bed height and conveyor speed, the capacity range may be extended even more. The design of the diffuser is such that unforeseen increases in capacity can, to a certain extent, be met by the addition of washing stages to existing diffusers;
- absence of fermentation: the diffusers are designed to eliminate all static zones where fermentation could develop. The return span of the diffuser conveyor is washed at every cycle to prevent contamination of the feed by pieces of bagasse sticking to the screen. The diffuser is fitted for pH control and for operation at optimum temperature;
- bagasse discharge is by gravity at the tail end of the diffuser: a special scraper is provided to even out the flow of bagasse and provide a continuous feed to the dewatering mills. The diffuser can be completely discharged for long stops and must not be cleaned manually;
- juice quality is good: systematic clarification of last mill juice enables removal of impurities early in the process and contributes towards the production of juices which are easy to clarify and which present no problems in the boiling house;
- heat economy: all heaters are of the type used for mixed juice heating in sugar factories. The diffuser is completely enclosed and insulated.

The continuous diffuser gives high yield on the extraction and low power consumption, and also the juice has low amount of interfering and contaminants that must be removed before the concentration step.

Figure 23: degree Brix curves: (1) sweet sorghum stalks diffuser, (2) bagasse diffuser
If sweet sorghum juice contains soluble solids (e.g. anthocyanins and chlorophyll) and insoluble solids (e.g. starch granules), these components have to be separated to process the sugar juice to bioethanol.

Good quality juice can be made after carrying out evaporation with continuous skimming of coagulated materials, which have risen to the surface. Evaporation should be done with uniform heating. Initially coagulation starts when juice temperature increases. This scum should be removed during slow heating. Evaporation should not be done fast as scum gathered on the top of the juice may get dissolved during rapid boiling and then floating or settled mass problems may be seen in the syrup.

The evaporation of the sugar juice must be done with a good quality product, eliminat-

---

**Figure 24: continuous diffuser**

**Figure 25: data for the design of a continuous diffuser**

<table>
<thead>
<tr>
<th>NOMINAL CAPACITY</th>
<th>METRIC TONS/DAY</th>
<th>FROM 2,000 TO 15,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRINCIPAL WIDTH M</td>
<td>2.8 3.3 4.2 4.7 5.2 5.7 6.2 6.7 7.2 7.7 8.2 8.7 9.2 9.7 10.9 11.4 11.9 13.4</td>
<td></td>
</tr>
<tr>
<td>WIDTH FT</td>
<td>9.2 10.7 13.8 15.4 17.0 18.7 19.6 22.0 23.6 25.3 26.9 28.6 30.2 31.8 35.7 37.4 39.0 44.0</td>
<td></td>
</tr>
<tr>
<td>OVERALL LENGTH</td>
<td>FROM 48.3 M - 158 FT</td>
<td>TO 61 M - 200 FT</td>
</tr>
<tr>
<td>INSTALL POWER</td>
<td>APPROX. 110 HP/1,000 TONS/DAY</td>
<td>APPROX. 100 HP/1,000 TONS/DAY</td>
</tr>
<tr>
<td>STEAM CONSUMPTION</td>
<td>KG/TON OF CANE</td>
<td>80 - 85</td>
</tr>
</tbody>
</table>
ing the solids content and other interfering. This purification can be done with the addition of lime and CO₂ for flocculating these compounds and eliminating them by filtration. Once the juice is clarified, the evaporation process carries out. The evaporation process will be done in a falling film evaporator working under vacuum to ensure the minimum energetic consumption and the best quality of the sugar juice. The previously clarification is needed to ensure the reduction of incrustations and soiling on the pipes and on the concentration unit.

8.3.2 Falling film evaporator
The concentration is the strategy chosen to preserve sugars and to supply the plant in the months after the harvesting of the sweet sorghum biomass. This section is required in both cases: sweet sorghum as sole feedstock and sweet sorghum and another raw material as feedstock.
The aim of this stage is the concentration of the sugar juice from 12-16 °Brix to 45-85 °Brix, depending on the storage period for the concentrated juice. This process increases the osmotic pressure in the liquid and avoids any bacterial or yeast development.
The falling film evaporator concentrates the sugar juice in several steps (between 2 and 4, depending on the final concentration), working under vacuum to ensure a low temperature process, lower steam consumption, and lower sugar degradation. At each concentration step, the diameter of the tubes of the falling film evaporator is increased to reduce fouling and to maintain the performance of concentration. From this step, the water condensed after the concentration could be used on the sugar extraction unit, minimizing the water consumption on the total process.

8.3.3 Fermentation unit
The fermentation is carried out by yeasts (Saccharomyces cerevisiae) at the conditions which favour firstly their quick cell growth and division and afterwards their anaerobic metabolism.
Especially the following conditions are required:
• glucose concentration > 9 g/l (in order to benefit from the Crabtree effect and to ensure the alcoholic fermentation instead of the oxidative metabolism);
• pH 4-5;
• temperature in the range 30-35 °C;
• nitrogen concentration 150-180 mg/l (as ammonium).
The fermentation unit has five sections.
1. Pasteurisation of sugar juice: in order to avoid unchecked fermentations by bacteria, sugar juice is sterilised through the pasteurisation (Table 24).
2. Preparation of yeasts: yeasts are re-hydrated and stabilized in order to obtain the suspension in the mother tank. This step is carried out with a solution rich in
glucose, fructose or sucrose, an average temperature of 35 °C and with the addition of bactericide, oxygen and eventually ergosterol. At the beginning of each fermentation reaction, an amount of the mother suspension is flowed as inoculum in the fermentation tank.

3. **Fermentation**: it can be applied in a batch process or in continuous one.
   - **Batch fermentation**: the fermentation reactions are performed in independent reactors without direct communications among them. The bioethanol yield of this process depends on the tolerance of yeast to the alcoholic concentration in the medium (maximum tolerance 19% v/v for selected strains). Although in this process the yield is lower than the yield of the continuous one, the control of contaminations is better and consequently the security is higher because this system allows an easy isolation of the contaminated tank, preventing that it can extend throughout all the unit.

   - **Continuous fermentation**: The continuous process is set up flowing the pasteurised sugar juice only to the first tank where yeasts is inoculated. From the first tank the partially fermented juice flows to the following ones; in this transit bioethanol is removed and its concentration in the medium maintains inferior to the inhibition level of yeasts. Then the fermentation by degrees continues until the last tank, where all the free sugars are converted in bioethanol. The yield of this process is higher than the yield of the batch one, because yeasts are not inhibited. Furthermore, the necessary capacity is less than the volume required by the other one. The main criticism is the contamination risk: in fact if one of the continuous tanks is contaminated with bacteria, the total system can be contaminated and the decontamination is more difficult.

4. **Recovery of yeasts**: The recovery of yeasts at the end of the fermentation process is a measure to increase the economic viability of the plant. Yeasts are recovered from the fermented medium through centrifugation. If yeasts are yet vital, they are reused in the fermentation process. If yeasts have finished their own lifetime, they are a source of proteins for the preparation of human and/or animal feed.

### 8.3.4 Distillation and rectification unit

The bioethanol concentration in the fermented medium is 9-14% v/v and the objective of this unit is to obtain the azeotropic bioethanol (i.e. 95-96% v/v).

At this aim the fermented medium flows through some distillation columns (i.e.
multiple effect distillation) made of bubbling dishes, where water and alcohol are separated basing on their own specific boiling points as they run up the tower. The multiple effect technology allows to reduce the heat consumption of this unit, because the pressure on the column head is lower than the atmospheric value and the boiling point of the components to separate is inferior.

**8.3.5 Dehydration unit**

The dehydration process is necessary to produce anhydrous bioethanol (i.e. 99.7-99.8% w/w). This value of purity is required to produce bio-ETBE or to blend bioethanol directly with petrol.

The dehydration unit is based on the molecular sieve technology: zeolite, which is the component of the sieves, retains selectively the residual water molecules, increasing gradually the percentage of bioethanol in the flowing blending.

Anhydrous bioethanol has to be stored in tanks with controlled atmosphere (free of air, usually with N₂ or CO₂), in order to avoid the solubilization of water vapour. The same conditions have to be applied in the transport phase.

**8.4 Energetic exploitation of the by-products**

**8.4.1 Bagasse**

Basing on its own characteristics (Table 25), the dried bagasse, residue of the extraction unit, can be burnt in CHP plant to produce electricity and heat.

The size of the CHP plant is correlated to the bagasse availability and then to the agricultural land cultivated with sweet sorghum and to its biomass yield.

Considering the biomass yields reported in Table 22 and the LHV of Table 25, the reference values in order to design the unit for the combustion of bagasse in CHP plant are reported in Table 26.

<table>
<thead>
<tr>
<th>Bagasse characterisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture after crushing</td>
</tr>
<tr>
<td>Residual sugars</td>
</tr>
<tr>
<td>Cellulose</td>
</tr>
<tr>
<td>Hemicellulose</td>
</tr>
<tr>
<td>LIGNIN</td>
</tr>
<tr>
<td>LHV</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy exploitation of bagasse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of environment</td>
</tr>
<tr>
<td>Type MEDITERRANEAN</td>
</tr>
<tr>
<td>Low fertility soils Dry climate</td>
</tr>
<tr>
<td>Bagasse yield</td>
</tr>
<tr>
<td>Available energy</td>
</tr>
<tr>
<td>Type TEMPERATE</td>
</tr>
<tr>
<td>Medium fertility soils Temperate oceanic climate</td>
</tr>
<tr>
<td>Bagasse yield</td>
</tr>
<tr>
<td>Available energy</td>
</tr>
<tr>
<td>Irrigation (emergency)</td>
</tr>
<tr>
<td>Bagasse yield</td>
</tr>
<tr>
<td>Available energy</td>
</tr>
<tr>
<td>Irrigation (emergency)</td>
</tr>
<tr>
<td>Bagasse yield</td>
</tr>
</tbody>
</table>

**Table 25: main characteristics of bagasse, obtained in a TRPF milling system, to plan its energetic exploitation**

**Table 26: main elements for the dimensioning of the unit of bagasse exploitation in some reference type of environments**
As regards with the technical details of the CHP plant, it is kitted out with a biomass burner, suitable to the combustion of herbaceous feedstock, and a turbine, which could be for example a steam turbine based on the Rankine-Hirn cycle, a gas turbine based on the Brayton cycle, or a turbogenerator based on the ORC cycle.

The choice of the technology for the CHP plant depends, most of all, on the electric power. The Figure 27 summarises some situations for the power values in the range interesting for the EU model (0.1-10 MWe) with the related energy efficiency.

The main criticism of the combustion of sorghum bagasse is the high content in ashes (3-5% db) that are characterised by a low melting point. Consequently, the technology applied in the biomass burner requires an adequate ash removal system and the special extended warranty has been issued by the manufacturer. The management of ashes depends on the law of the specific country.

8.4.2 Vinasse

Vinasse, residue of the distillation and rectification units, has a chemical composition which is suitable to the production of biogas through the anaerobic digestion (Table 27).

The dimensioning of the anaerobic digester is correlated to the vinasse availability and then to the capacity as anhydrous bioethanol and to the HRT.

Concerning the vinasse yield, the theoretical correlation coefficient is 7-8 litre of vinasse per litre of bioethanol.

As regards with the HRT to complete the biomethanation, it depends on the chemical composition of the feedstock: as a principle, lignin, cellulose, protein show a slower degradation than fats, starch and sugars. The methanogenesis of vinasse is carried out using also other substrates to start up and/or stabilise the process: for example manure is utilised as microbial inoculum at the beginning of the process and lignocellulosic feedstock can be mixed to vinasse to improve the ratio between carbon and nitrogen, if necessary. In this hypothesis the HRT for vinasse is 60 days approximately.

The typical chemical composition of biogas is reported in the Table 28.

The theoretical methane yield is 0.395 Nm³ per kilogram of COD, if the content of methane in biogas is 60%.

Assuming the yields in vinasse and methane and the values of Table 27 and Table 28 for COD and LHV respectively, the elements to dimension this unit are summarised in Table 29.
The obtained biogas is burnt in a CHP plant which can be based on Diesel engine or gas micro-turbine.

The utilised Diesel engine requires some modifications in order to work with the Otto cycle in the combustion of methane: especially it is fitted out with a carburettor and the spark plugs. At the current time these modified engines are already available on the market. Heat is recovered through a exchanger from the flue gases and/or from the engine cooling.

The energy efficiency is correlated with the electric power of the CHP plant: in the range considered for the EU model (0.1-5.0 MWe) the electrical efficiency is 30-42%, the thermal efficiency is 45-50%. The highest powers are characterised by the most efficiency, above all in the electric conversion.

The digested matter, residue of the biomethanation, is a good fertiliser (nitrogen 800 g/t, mainly as ammonium) and it is applied in the fields in order to compensate the nitrogen removal carried out by sweet sorghum growth.

<table>
<thead>
<tr>
<th>Biogas characterisation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>50-70%</td>
</tr>
<tr>
<td>CO₂</td>
<td>25-45%</td>
</tr>
<tr>
<td>H₂</td>
<td>1-10%</td>
</tr>
<tr>
<td>N₂</td>
<td>0.5-3.0%</td>
</tr>
<tr>
<td>CO</td>
<td>0.08-0.10</td>
</tr>
<tr>
<td>H₂S</td>
<td>0.02-0.20</td>
</tr>
<tr>
<td>O₂</td>
<td>traces</td>
</tr>
<tr>
<td>LHV</td>
<td>21-22 MJ/Nm³</td>
</tr>
<tr>
<td></td>
<td>5.8-6.1 kWh/Nm³</td>
</tr>
</tbody>
</table>

Table 28: main characteristics of biogas

<table>
<thead>
<tr>
<th>Energy exploitation of vinasse</th>
<th>Type of environment</th>
<th>Yield *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type MEDITERRANEAN</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low fertility soils</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry climate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>340-1,030 Nm³/ha</td>
</tr>
<tr>
<td></td>
<td>Available energy</td>
<td>7.9-23.7 GJ/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.2-6.6 MWh/ha</td>
</tr>
<tr>
<td></td>
<td>Type TEMPERATE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium fertility soils</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperate oceanic climate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>500-790 Nm³/ha</td>
</tr>
<tr>
<td></td>
<td>Available energy</td>
<td>11.6-18.4 GJ/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2-5.1 MWh/ha</td>
</tr>
<tr>
<td></td>
<td>Irrigation (emergency)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>1,070-1,420 Nm³/ha</td>
</tr>
<tr>
<td></td>
<td>Available energy</td>
<td>24.9-32.7 GJ/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.9-9.1 MWh/ha</td>
</tr>
</tbody>
</table>

* calculations with the application of the actual methane yield

Table 29: main elements to the dimensioning of the unit of vinasse exploitation in some reference type of environments
9. THE EU MODEL 1: SWEET SORGHUM AS SOLE FEEDSTOCK OF THE PLANT

This model is aimed to develop a chain in the EU based only on sweet sorghum as feedstock.

The main advantage of this model is the utilisation of a crop which is characterised by low agricultural inputs (i.e. water and fertilisers).

The main disadvantage of this model is the dependence of the plant from a single type of raw material.

In order to explain this model for the EU, the guidelines described in the previous chapter are applied to an exemplifying plant with capacity as anhydrous bioethanol of 10,000 t/year.

The main details of this application are summarised in Table 30.

Concerning the agricultural land requirement, in the temperate climate characterised by medium fertility soils and rainfall of about 600-700 mm during the growth period, 3,000-4,800 hectares are required. If the emergency irrigation is foreseen, the higher yield allows to reduce the cultivated surface to 1,700-2,300 hectares, but in this situation the agricultural costs increase significantly and usually maize or other crops becomes more competitive. Consequently, this important variable has to be taken into consideration in choosing the fields to cultivate and in the related feasibility study.

On the contrary in the Mediterranean conditions the irrigation is necessary to obtain viable yields. A surface of 2,200-6,600 hectares is required; the high width of the range is due to the very different values in the yields, which depend on the inputs of water and fertilisers.

The decision about the range of supply is correlated to different factors, such as technical, logistical, energetic, economic ones. Firstly, the competitiveness of sweet sorghum compared to other crops depends by its economic viability which is the prerequisite, but also by the agricultural tradition of the specific area and by the propensity to innovation of the farmers. Some indicators can be utilised in this evaluation, for example the crop diversification and the farm structure. If the crop diversification in the considered area is high, it is plausible that the range of supply increases, because this suggests that numerous crops are competitive and the market repays all of them. On the contrary, the low age of farmers, the big size of farms and the application of innovative solutions in the agricultural practices usually indicate a possible decrease in the range of supply. Secondly, the decision must be subjected to the LCA and to the analysis of the logistics, evaluating the energetic and environmental impacts of each hypothesized value for the range of supply. Finally, the assumed range of supply must allow to benefit from eventual national incentives that the different countries make available for the RES.

As regards with the logistics, the harvesting operations are carried out in yards; each one of them is fitted out with 1 mower-shredder-loader machine and 4-6 farm tractors fitted out with dumper (i.e. capacity about 50 m³) for the transport of the chopped biomass to the plant.

Regardless the number of hectares and the range of supplying, every year 68,000-
| Dimensioning of chain supply | Agricultural land | Type Mediterranean  
2,200-6,700 ha  
Type Temperate  
3,000-4,800 ha (no irrigation)  
1,700-2,300 ha (emergency irrigation)  
| Range of supply | It depends on the specific region, for example in terms of crop diversification, farm structure, limits for the incentives to short agro-energy chains  
| Operational details | Processing of sugar juice  
330 working days per year  
68,000-69,000 t db of sweet sorghum biomass crushed in 40 days  
Crushing, fermentation, distillation, rectification and dehydration in accordance with the guidelines  
| Concentration unit | Storage  
Syrup at 45% storable up to 3 months  
Syrup at 80% storable up to 11 months  
Utilisation  
Dilution to 18%  
Water management  
Waste water discharged into surface water body in accordance with the national and local laws  
Purchase of water for the dilution  
Thermal consumption  
Self-consumption from the by-products exploitation  
0.43 MWe available at the end of the harvesting period  
| Bagasse | Availability  
41,850-42,460 t db of bagasse to store, dry and burn during all year  
711.4-764.3 TJ/year  
196.69-212.31 GWh/year  
| Energetic exploitation of by-products | CHP plant  
4.20 MWe  
| Ashes | 2,040-3,450 t/year  
Disposal in landfills or other management, depending on the different countries  
| Vinasse | Availability  
Capacity of the anaerobic digester 20,000-22,000 m³ (HRT 60 days)  
Capacity of the biogas storage 10,000-14,000 m³  
14.0-14.7 TJ/year  
3.86-4.06 GWh/year  
| CHP plant | 0.75 MWe  
| Digested matter | 93,000-95,000 t/year  
Use as fertiliser  
74-76 t/year of nitrogen (mainly ammonium)  

Table 30: main details related to the EU model to process sweet sorghum as sole feedstock in a plant with capacity 10,000 t/year as anhydrous bioethanol
69,000 tons of biomass are processed in the plant to obtain 1st generation bioethanol from the sugar juice and electricity and heat from the by-products.

The biomass supply to the plant occurs only during the harvesting period: 40 days at maximum between August and September in the South EU climate conditions. On the contrary, the working period of the plant is 330 days per year; in fact one plant shutdown is foreseen approximately in July for the planned maintenance.

To preserve sugars during the entire working period of the plant, the chopped biomass is immediately crushed at the moment of the delivery and the obtained sugar juice is concentrated for the storage and processing in the period after the harvest. The final sugar concentrations of the syrup are 45% for the storage up to 3 months and 80% for the storage up to 11 months. The concentrated syrups are stored in adequate tanks at the plant.

The syrup is diluted before the inoculum with the mother suspension of yeasts; afterwards the fermentation is started up with an in batch process and the duration is set up in 22 hours.

As regards with the other technical aspects of the processing, the fermentation, distillation, rectification and dehydration phases are carried out in accordance with the guidelines described in the chapter 7.

A special explanation is necessary in this model for the water management, because a relevant amount of water is evaporated and then condensed and afterwards an important amount of water is required for the dilution of the syrup.

In the considered model this potential criticism is solved assuming that waste water of the concentration unit is discharged into surface water body (in accordance with the limits foreseen by the national and eventual local laws in terms of COD, nitrate, pH, phosphate, temperature and other chemical and physical parameters), whereas the potable water for the dilution is bought. This assumption appears preferable from technical and economic points of view if compared to the choice of storing waste water and using it the next dilution, because in this second case too high storage volumes are required.

Concerning the energetic exploitation of the by-products, bagasse is dried and then burnt in CHP plant fitted out with steam turbine (electric power 4.20 MWe), and biogas, obtained from vinasse through the anaerobic digestion, is burnt in a CHP plant based on a gas turbine (electric power 0.75 MWe). Electricity and heat, produced in these units, can be used for the self-consumption and the surplus of both of them is sold to the electric grid and distributed through a district heating network.

When the concentration unit stops working (i.e. at the end of harvesting period), a relevant thermal consumption lacks in the plant and consequently the correspondent energy can be converted in electricity with a small steam turbine (electric power 0.43 MWe), increasing the total production.

9.1 Case study: the development of the EU model 1 in the Po Valley in Italy

9.1.1 Specific assumptions
The chain model to process sweet sorghum as sole feedstock in a plant of capacity
10,000 t/year (as anhydrous bioethanol) is applied in the case study contextualised to the Po Valley, in North East Italy. This area has an agricultural tradition and sown crops are prevalent. The specific situation of the considered area is summarised in Table 31.

The agricultural land assumed in the case study is 3,800 hectares and the range of supply with the specific characteristics of the area is 15 km.

Taking into consideration the crop diversification and the farm structure of the area, the localisation of the fields is hypothesised as follows: 35% of the fields within 5 km from the plant, 44% of fields from 6 to 11 km from the plant, 21% of fields from 12 to 15 km from the plant. In this scenario the harvest requires 4 parallel yards; in each one 1 mower-shredder-loader machine and 6 farm tractor fitted out with dumper work; the consequent traffic is 15 tractor per hour during the 40 days of harvesting.

In this climate the duration of the harvesting period can last up to 40 days, if short cycle varieties and long cycle ones are cultivated at the same time in different fields of the considered agricultural surface.

The main details of the agricultural phase are reported in Table 32.

The production of 1st generation bioethanol is carried out in accordance with the guidelines. The utilised crusher has an efficiency of 93%; consequently the sugar concentration is 12.4% in the juice and 5.4% db in the bagasse. Bagasse has a residual moisture of 31%. As regards with the concentration unit, the continuous supply of the fermentation reactors is planned for concentrating at 80% most of the sugar juice (73% of the total amount) and at 45% the residual part (27% of the total amount). The following fermentation of the newly diluted sugar juice is carried out with a batch process. The applied efficiency of the alcoholic fermentation is 90% of the theoretical one.

The obtain anhydrous bioethanol has purity of 99.7% w/w and it is suitable to produce bio-ETBE or for bending with petrol.

Concerning the by-products exploitation, wet bagasse is stored and dried up

<table>
<thead>
<tr>
<th>Po Valley, North East Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climatic characteristics</td>
</tr>
<tr>
<td>Soil type</td>
</tr>
<tr>
<td>Rainfall in the growth period</td>
</tr>
<tr>
<td>Sowing time</td>
</tr>
<tr>
<td>Harvesting time</td>
</tr>
<tr>
<td>Crop diversification</td>
</tr>
<tr>
<td>Farm structure</td>
</tr>
</tbody>
</table>

Table 31: main characteristics of the geographic area considered in the case study

Agricultural phase *

<table>
<thead>
<tr>
<th></th>
<th>100 kg N/ha</th>
<th>60 kg P₂O₅/ha</th>
<th>60 kg K₂O/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilisation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass yield</td>
<td>18.2 t/ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar yield</td>
<td>6.5 t/ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anhydrous bioethanol yield</td>
<td>2.8 t/ha</td>
<td>3.5 m³/ha</td>
<td>75.6 GJ/ha</td>
</tr>
<tr>
<td>Previous land use</td>
<td>Maize</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* reference year: 2010

Table 32: main detail of the cultivation of sweet sorghum in the case study
to 10% immediately before the burning in the CHP plant. During the storage a biomass loss of 5% is hypothesized (mainly sugars). The CHP plant is fitted out with a biomass burner, a steam generator and a steam turbine; its thermal efficiency is 0.90. Unlike the other units, this CHP plant works for 340 days per year. Biogas obtained from vinasse supplies a gas micro-turbine with electrical efficiency of 34%.

In this case study, electricity is sold to the grid and heat is used for the self-consumption of the plant.

Electricity is sold to the grid because at the current time a relevant incentive system is available in Italy for the RES and especially for biomass. Consequently, the economic balance benefits from the selling of produced electricity and from the contextual purchase of the amount to consume in the plant.

Produced heat can cover the thermal consumption of the plant. The highest consumptions are relative to the following units: the concentration of the sugar juice (only during the harvesting period), the distillation and rectification units, the drying of the bagasse. In this case study the selling of heat through a district heating network is not considered, because there is a reasonable difficulty in the considered area in finding users.

Apart these assumptions, the case study applies the contents of the EU model 1.

9.1.2 Economic analysis

The main costs and incomes considered in the economic analysis are summarised in Table 33.

<table>
<thead>
<tr>
<th>Economic analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investment cost</strong></td>
</tr>
<tr>
<td><strong>Operative costs</strong></td>
</tr>
<tr>
<td>Biomass 20-35 €/t *</td>
</tr>
<tr>
<td>O&amp;M</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td><strong>Incomes</strong></td>
</tr>
<tr>
<td>Final products</td>
</tr>
<tr>
<td>Bioethanol price 400-1,000 €/t *</td>
</tr>
<tr>
<td>Supported electricity price 0.18-0.28 €/kWh *</td>
</tr>
</tbody>
</table>

* variable subjected to the sensitivity analysis

Table 33: main costs and incomes included in the economic analysis of the case study

The investment costs include buildings, equipment, extraordinary maintenance, overheads (5%), technical costs (5%), unforeseen expenses (4%); land acquisition, eventual licenses and patents are not included.

In the operative costs the purchase of chemicals, the water management (i.e. discharge of waste water from the concentration unit, purchase of potable water for the syrup dilution), the disposal of ashes, the biomass moving and the insurance are included in the item called “Other”.

The price of biomass and the values for the incomes are reported as range because these parameters are variables for the related sensitivity analyses.

The adequate reward of farmers as biomass suppliers is the prerequisite for the devel-
<table>
<thead>
<tr>
<th>IRR (€/t)</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>-6.2%</td>
<td>4.1%</td>
<td>10.5%</td>
<td>15.7%</td>
<td>20.2%</td>
<td>24.5%</td>
<td>28.5%</td>
</tr>
<tr>
<td>200</td>
<td>1.4%</td>
<td>8.7%</td>
<td>14.3%</td>
<td>19.1%</td>
<td>23.4%</td>
<td>27.5%</td>
<td>31.4%</td>
</tr>
<tr>
<td>220</td>
<td>6.7%</td>
<td>12.8%</td>
<td>17.8%</td>
<td>22.3%</td>
<td>26.5%</td>
<td>30.5%</td>
<td>34.4%</td>
</tr>
<tr>
<td>240</td>
<td>11.2%</td>
<td>16.5%</td>
<td>21.2%</td>
<td>25.5%</td>
<td>29.6%</td>
<td>33.5%</td>
<td>37.3%</td>
</tr>
<tr>
<td>260</td>
<td>15.1%</td>
<td>20.0%</td>
<td>24.5%</td>
<td>28.6%</td>
<td>32.6%</td>
<td>36.4%</td>
<td>40.2%</td>
</tr>
<tr>
<td>280</td>
<td>18.8%</td>
<td>23.4%</td>
<td>27.6%</td>
<td>31.7%</td>
<td>35.6%</td>
<td>39.4%</td>
<td>43.1%</td>
</tr>
</tbody>
</table>

Table 34: IRR values varying the bioethanol and electricity market, if the price of biomass is 20 €/t.

<table>
<thead>
<tr>
<th>IRR (€/MWh)</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>-</td>
<td>-10.7%</td>
<td>2.4%</td>
<td>9.2%</td>
<td>14.6%</td>
<td>19.3%</td>
<td>23.6%</td>
</tr>
<tr>
<td>200</td>
<td>-</td>
<td>-0.7%</td>
<td>7.4%</td>
<td>13.2%</td>
<td>18.1%</td>
<td>22.5%</td>
<td>26.6%</td>
</tr>
<tr>
<td>220</td>
<td>-5.3%</td>
<td>5.2%</td>
<td>11.6%</td>
<td>16.8%</td>
<td>21.4%</td>
<td>25.6%</td>
<td>29.7%</td>
</tr>
<tr>
<td>240</td>
<td>2.5%</td>
<td>9.9%</td>
<td>15.4%</td>
<td>20.2%</td>
<td>24.6%</td>
<td>28.7%</td>
<td>32.6%</td>
</tr>
<tr>
<td>260</td>
<td>7.9%</td>
<td>14.0%</td>
<td>19.0%</td>
<td>23.5%</td>
<td>27.7%</td>
<td>31.7%</td>
<td>35.6%</td>
</tr>
<tr>
<td>280</td>
<td>12.4%</td>
<td>17.7%</td>
<td>22.4%</td>
<td>26.7%</td>
<td>30.8%</td>
<td>34.7%</td>
<td>38.6%</td>
</tr>
</tbody>
</table>

Table 35: IRR values varying the bioethanol and electricity market, if the price of biomass is 25 €/t.

<table>
<thead>
<tr>
<th>IRR (€/MWh)</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.5%</td>
<td>7.9%</td>
<td>13.5%</td>
<td>18.3%</td>
</tr>
<tr>
<td>200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.3%</td>
<td>5.9%</td>
<td>12.0%</td>
<td>17.0%</td>
</tr>
<tr>
<td>220</td>
<td>-</td>
<td>-</td>
<td>-10.1%</td>
<td>3.5%</td>
<td>10.3%</td>
<td>15.7%</td>
<td>20.4%</td>
</tr>
<tr>
<td>240</td>
<td>-</td>
<td>0.4%</td>
<td>8.5%</td>
<td>14.3%</td>
<td>19.2%</td>
<td>23.7%</td>
<td>27.8%</td>
</tr>
<tr>
<td>260</td>
<td>-4.2%</td>
<td>6.3%</td>
<td>12.8%</td>
<td>18.0%</td>
<td>22.6%</td>
<td>26.8%</td>
<td>30.9%</td>
</tr>
<tr>
<td>280</td>
<td>3.7%</td>
<td>11.0%</td>
<td>16.6%</td>
<td>21.4%</td>
<td>25.8%</td>
<td>29.9%</td>
<td>33.9%</td>
</tr>
</tbody>
</table>

Table 36: IRR values varying the bioethanol and electricity market, if the price of biomass is 30 €/t.

<table>
<thead>
<tr>
<th>IRR (€/MWh)</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-1.7%</td>
<td>6.5%</td>
<td>12.4%</td>
</tr>
<tr>
<td>200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-6.6%</td>
<td>4.3%</td>
<td>10.8%</td>
</tr>
<tr>
<td>220</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.5%</td>
<td>9.0%</td>
<td>14.6%</td>
<td>19.4%</td>
</tr>
<tr>
<td>240</td>
<td>-</td>
<td>-</td>
<td>-2.2%</td>
<td>7.0%</td>
<td>13.1%</td>
<td>18.2%</td>
<td>22.7%</td>
</tr>
<tr>
<td>260</td>
<td>-</td>
<td>-9.3%</td>
<td>4.6%</td>
<td>11.5%</td>
<td>16.9%</td>
<td>21.6%</td>
<td>25.9%</td>
</tr>
<tr>
<td>280</td>
<td>-</td>
<td>1.6%</td>
<td>9.7%</td>
<td>15.5%</td>
<td>20.4%</td>
<td>24.9%</td>
<td>29.1%</td>
</tr>
</tbody>
</table>

Table 37: IRR values varying the bioethanol and electricity market, if the price of biomass is 35 €/t.
opment of the chain. Consequently, the quantification of the biomass price requires a very precautionary approach. Assuming that in the considered area the agricultural costs correspond to 16-18 €/t wb (equivalent to 1,040-1,170 €/ha, including the transport to the plant with an average distance of 10 km), the affordability threshold is estimated at 30 €/t. In fact, in worse conditions other crops become more competitive than sweet sorghum and then the security of supply becomes critical.

However, the lower values of the range are included in the sensitivity analysis, because the economic viability of the chain model must foresee wide scenarios in order to evidence all the possible solutions in changing the market conditions (e.g. fall down of the bioethanol price, decrease of the national support to the RES).

The price of bioethanol depends on the energy market, especially on the oil price, and the considered range is believed precautionary.

As regards with the incomes from the electricity selling, at the current time in Italy the use of biomass allows to access to 2 alternative incentives, which are valid for 15 years:

a. the total income derives from the sum of the item due to the selling of electricity (based on the market price) and the value for the correspondent Green Certificates, the number of which is multiplied by a coefficient, which is specific for each RES (i.e. 1.8 for biomass and biogas);

b. the total income derives just from an all-inclusive tariff, the value of which depends on each RES (i.e. 0.28 €/kWh for biomass and biogas).

The second option is usually preferable, because it is not influenced by the energy market and consequently it allows incomes foreseeable for 15 years. Nevertheless at the current time this option is available only for electric power inferior to 1 MWe. The possibility to extend this incentive to higher electric powers (at least 5 MWe) is foreseen by the Italian law, but is not yet really applied because the regulations are lacking.

Taking into consideration the electric powers applied in this case study (i.e. 4.20 MWe from bagasse, 0.75 MWe from vinasse, 0.43 MWe from the concentration unit) and the related uncertainties, the range from 0.18 to 0.28 €/kWh is considered as precautionary.

The economic availability of the initiative is established for IRR values higher than 20%, because they ensure the bankability and significantly higher profits than the rate debit.

The results of the sensitivity analyses are summarised in the following four tables, where for each price of the biomass in the considered range (i.e. 20 €/t, 25 €/t, 30 €/t, 35 €/t) the IRR values are reported varying the market conditions: bioethanol and electricity prices in the rows and columns, respectively. In yellow the viable theses are evidenced; the darker cells indicate the conditions with IRR higher than 30%.

The threshold value for the adequate reward of farmers (i.e. 30 €/t) is viable for at least 900 €/t for bioethanol and 0.22 €/kWh for electricity or at least 1,000 €/t for bioethanol and 0.20 €/kWh. At the current time in Italy these scenarios are likely and then the certainty of supply could be ensured.

9.1.3 GHGs emissions saving

Cultivation phase

The emissions deriving from cultivation section include all the agronomic parts of the chain, as follows:
1. the input data of the biomass yield in the Po Valley (North East Italy) is 65 t/ha wb (moisture 72%), specifically expressed in 65,000 kg/ha/year, and the correspondent energetic output of 316,680 MJ sorghum/ha/year is calculated;

2. the energy consumption has been calculated considering the sum of primary energy, fuels and lubricants for the machineries for cultivation in the specific case study: it corresponds to 5,563 MJ/ha/year;

3. the agrochemicals inputs have been reported as really used in the case study for sorghum cultivation: N 100 kg/ha/year, K₂O 60 kg/ha/year, P₂O₅ 60 kg/ha/year. Pesticides and herbicides have been calculated as 2 kg/ha/year;

4. the vinasse deriving from the distillation and rectification units is not considered to utilise as fertiliser because it is used in anaerobic digestion section for biogas production. Otherwise, the residual digested matter after biogas production is considered as source of organic fertilisation for sorghum cultivation. The amount has been calculated considering the production of digested matter which is 92,705 t/year to share in 3,800 ha, and the resulting amount is 24,396 kg/ha/year;

5. the seeding material used in the case study is 10 kg/ha/year;

6. the field N₂O emissions have been calculated using the specific tool “N₂O emissions IPCC”. The biomass yield is 65,000 kg/ha/year wb (moisture 72%). The land use is from arable to arable land. In the direct N₂O emissions from managed soils the inputs are 100 kg N/ha/year of synthetic fertiliser and 19.52 kg N/ha/year of organic fertiliser considering the application of digested matter that corresponds to 19.52 kg N/ha. The indirect N₂O emissions are automatically calculated. The N₂O resulted emissions are 3.06 kgN₂O/ha/year.

The emissions from cultivation phase correspond to 29.32 gCO₂/MJbioethanol.

The transport of digested matter to the fields for the organic fertilisation is included in the cultivation phase. The transport is considered with tanker trucks with water cannons for 20 km (this is the average value for the transport of biomass in the case study). The resulting amount is 0.56 gCO₂/MJbioethanol which is summed to the previous number.

<table>
<thead>
<tr>
<th>Cultivation phase</th>
<th>kg/ha/year</th>
<th>MJsorghum/ha/year</th>
<th>MJ/ha/year</th>
<th>gCO₂/MJbioethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass yield</td>
<td>65,000</td>
<td>316,680</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>-</td>
<td>-</td>
<td>5,563</td>
<td>6.81</td>
</tr>
<tr>
<td>N</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>8.22</td>
</tr>
<tr>
<td>K</td>
<td>60</td>
<td>-</td>
<td>-</td>
<td>0.48</td>
</tr>
<tr>
<td>P</td>
<td>60</td>
<td>-</td>
<td>-</td>
<td>0.85</td>
</tr>
<tr>
<td>Pesticides</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>0.31</td>
</tr>
<tr>
<td>Digested matter</td>
<td>24,396</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Seeding material</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Field N₂O emissions</td>
<td>3.06</td>
<td>-</td>
<td>-</td>
<td>12.66</td>
</tr>
<tr>
<td>Transport of digested matter</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.56</td>
</tr>
<tr>
<td>Total without allocation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>29.9 gCO₂/MJbioethanol</td>
</tr>
<tr>
<td>Total with allocation*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>26.7 gCO₂/MJbioethanol</td>
</tr>
</tbody>
</table>

*allocation factor 89%

Table 38: GHGs emissions from the cultivation phase
The emissions in GHGs for cultivation phase \( (e_{ec}) \) are 29.9 gCO\(_2\)/MJ\(_{\text{bioethanol}}\). With the allocation, the emissions corresponds to 26.7 gCO\(_2\)/MJ\(_{\text{bioethanol}}\) like reported in Table 38.

**Transport and distribution phases**

For the transport phase, the quantity of product is calculated in 316,680 MJ\(_{\text{sorghum}}\)/ha/year. The transport of biomass per truck for dry product with Diesel fuel is considered for the average value of 20 km. The partial value for emissions from this transport phase is 1.49 gCO\(_2\)/MJ\(_{\text{bioethanol}}\), but this value must be summed with the transport of bioethanol from the plant to depot and then to filling stations. For this part of the transport the allocation factor must be considered (89%), so the emissions are 1.33 gCO\(_2\)/MJ\(_{\text{bioethanol}}\).

For the transport of bioethanol from plant to and from depot:

1. the used trucks for liquids are considered of moving for 300 km as mean value of distance from the plant destinations inside EU;
2. the energy consumption depot has the same values reported for sugarcane bioethanol plants.

The resulting partial value is 1.31 gCO\(_2\)/MJ\(_{\text{bioethanol}}\). The allocation is not considered for this phase, where all is allocated on bioethanol (100%).

For the filling station the values are the same of bioethanol from sugarcane or other feedstocks. Correspondent value in emissions is 0.44 gCO\(_2\)/MJ\(_{\text{bioethanol}}\). The allocation is not considered for this phase, where all is allocated on bioethanol (100%).

For transport \( (e_{td}) \), the final value is 3.08 gCO\(_2\)/MJ\(_{\text{bioethanol}}\) (Table 39).

<table>
<thead>
<tr>
<th>Transport and distribution phase</th>
<th>km</th>
<th>Truck with Diesel fuel</th>
<th>MJ/ MJ(_{\text{bioethanol}})</th>
<th>gCO(<em>2)/MJ(</em>{\text{bioethanol}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport of harvested sweet sorghum*</td>
<td>20</td>
<td>Truck for dry product</td>
<td>-</td>
<td>1.49</td>
</tr>
<tr>
<td>Transport of bioethanol from plant</td>
<td>300</td>
<td>Truck for liquids</td>
<td>-</td>
<td>0.99</td>
</tr>
<tr>
<td>Energy consumption depot</td>
<td>-</td>
<td>-</td>
<td>0.00252</td>
<td>0.32</td>
</tr>
<tr>
<td>Filling station</td>
<td>-</td>
<td>-</td>
<td>0.0034</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Total without allocation</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>3.24 gCO(<em>2)/MJ(</em>{\text{bioethanol}})</strong></td>
</tr>
<tr>
<td><strong>Total with allocation</strong>*</td>
<td></td>
<td></td>
<td></td>
<td><strong>3.08 gCO(<em>2)/MJ(</em>{\text{bioethanol}})</strong></td>
</tr>
</tbody>
</table>

*allocation factor 89 %

**Table 39: GHGs emissions from the transport and distribution phases**

**Processing phase**

Basing on the data of the case study, 0.226 MJ\(_{\text{bioethanol}}\)/MJ\(_{\text{sorghum}}\) are produced.

In the sweet sorghum based model the total amount of electricity generated (CHP from bagasse burning, biogas burning and the turbine of the concentration section) is divided in electricity from by-products (biogas and concentration) that is allocated separately (89% bioethanol, 11% by-product), and electricity from CHP plant fed with the bagasse (this is totally attributed to bioethanol production). The
large excess of electricity produced by CHP plant is sold to the grid. From the total amount of electricity a part is re-used in the plant for the bioethanol production: it corresponds to 0.108 MJ/MJ_{bioethanol}.

Since electricity is produced in a larger amount than the requirement of the plant, this is not really a demand but a reduced electricity output. The output of electricity from the steam production is credited by the electricity from bagasse burnt in CHP plant with steam turbine for power generation. As a consequence, also the electricity demand in the bioethanol plant is considered to be electricity from bagasse burnt in CHP plant to acknowledge for the fact that in practice this is not a demand, but a reduced electricity output.

In the considered case study the total production (output) of electricity is 43,240 MWh (155,664 GJ) obtained from bagasse burning, biogas and concentration section. Subtracting the amount relative to by-products (8,996 MWh) the electricity produced just in the CHP with bagasse is 34,244 MWh (123,278 GJ), correspondent to 0.454 MJ/MJ_{bioethanol} on annual basis. Subtracting the electrical consumptions of the plant, the obtained value is 0.346 MJ/MJ_{bioethanol}: this is the surplus of electricity and the credit is calculated following RED Annex V, C.16.

The heat production is not considered, because it is completely re-used in the plant for internal needs.

The chemicals of the plant are used in the production processes and a part of them are lubricants for the machineries.

The emissions from the processing (e_p) correspond to -1.12 gCO_2/MJ_{bioethanol}. The details are summarised in Table 40.

<table>
<thead>
<tr>
<th>Processing phase</th>
<th>MJ_{bioethanol}/MJ_sorghum</th>
<th>MJ/MJ_sorghum</th>
<th>MJ_{bioethanol}/ha/year</th>
<th>MJ/MJ_{bioethanol}</th>
<th>gCO_2/MJ_{bioethanol}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield bioethanol</td>
<td>0.226</td>
<td>-</td>
<td>71,570</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>By-products</td>
<td>-</td>
<td>0.027</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electricity taken from CHP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.108</td>
<td>-</td>
</tr>
<tr>
<td>Steam from CHP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electricity generation (total)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.454**</td>
<td>-</td>
</tr>
<tr>
<td>Electricity bagasse Steam Turbine*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.346**</td>
<td>-1.98</td>
</tr>
<tr>
<td>Chemicals</td>
<td>-</td>
<td>-</td>
<td>0.00132 kg/MJ_{bioethanol}</td>
<td>-</td>
<td>0.85</td>
</tr>
<tr>
<td>Total without allocation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.12 gCO_2/MJ_{bioethanol}</td>
</tr>
<tr>
<td>Total with allocation***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.00 gCO_2/MJ_{bioethanol}</td>
</tr>
</tbody>
</table>

* surplus electricity, credit is calculated following RED Annex V C.16
** electricity output, so it is negative
*** allocation factor 89 %

Table 40: GHGs emissions from the processing phase

**Land use change and improved agricultural management**

Concerning the LUC in the sweet sorghum cultivation, the assumption is “no LUC”, because the cultivation of sweet sorghum in the case study is done in fields where
usually maize is cultivated. In fact the same techniques for maize are used for sweet sorghum and also the machineries and the type of soils are similar. The improved agricultural management, the CO$_2$ capture and replacement and for CO$_2$ capture and geological storage are not considered.

**GHGs emission saving in the case study**

The final value of emissions per mega joule of bioethanol obtained from sweet sorghum corresponds to 32.00 gCO$_2$/MJ$_{\text{bioethanol}}$. The fossil fuel reference (i.e. petrol) has the emission value of 83.8 gCO$_2$/MJ$_{\text{petrol}}$. The allocated result corresponds to 28.8 gCO$_2$/MJ$_{\text{bioethanol}}$.

The emission reduction resulting from the calculationforeseen in the RED corresponds to 66%. It complies with the objective to 2018.

This result is comparable to the values for bioethanol from sugarcane (i.e. 71% GHGs emissions saving as default value) and the bioethanol from wheat with straw burnt in CHP (i.e. 69% GHGs emissions saving as default value).

**Topic: Methodology for the calculation of GHGs emissions saving**

An important aspect of the model is relative to the GHGs emissions in the bioethanol production from sweet sorghum and in the power generation. The calculation of the LCA of this chain and the emissions of grams of CO$_2$ equivalents per mega joule of produced bioethanol can give the percentage of emissions saving of the bioethanol produced from sweet sorghum in Italy. The values are compared with the values given in the Annex V of the RED for other energy crops used for biofuels production.

For this purpose, the public “BioGrace greenhouse gas calculation tool” (www.biograce.net) is the instrument that can be used for the calculation of the GHGs saving producing bioethanol from sweet sorghum (as 1st generation bioethanol) and heat and power from the exploitation of by-products of the chain.

The BioGrace tool allows reproduction of the calculation of the Annex V default values of the RED for biofuels production pathways and also allows to perform individually adapted calculations.

In accordance with the guidelines for the EU model and especially with the assumptions of the case study of the model 1, the BioGrace tool has been used integrating the already created pathways of bioethanol from sugarcane, from maize, from wheat with the residual straw burnt in CHP plant. Integrating these three pathways and taking the parts of interest relatively to sweet sorghum, the final result were obtained for this crop.

An important consideration regards the fact that the model foresees a concept of biorefinery, where integrated chain is deriving from the 1st generation bioethanol production and the use of by-products for power generation in large excess if considered the requirements for the biofuel production.

Sweet sorghum is processed similarly to sugarcane, transporting the fresh harvested biomass to the plant, extracting the sugar juice to ferment to bioethanol, burning the bagasse in CHP unit. Consequently the main part of the values can be similar and/or compared to those of sugarcane.

In order to verify the goodness of the results obtained for sweet sorghum, which is a sowable crop unlike sugarcane, the cultivation data (e.g. fertilisers, period of sowing and harvesting, energy consumption in terms of machineries) have been compared to those of maize.

Furthermore the burning of bagasse in CHP plant is similar to the burning of bagasse of sugarcane but also to the burning of wheat straw (i.e. also the LHV of straw and bagasse are similar).
The electricity generated from the bagasse combustion is considered in the emissions of the plant; a part is reused in the bioethanol production, but a large amount is excess electricity that is counted in the emissions of the bioethanol plant section.

The biogas obtained from the anaerobic digestion of the vinasse is then burnt in CHP plant and the electricity is sold to the grid; the same happens for the electricity generated from concentration section with the condensation turbine. For these two sections, the electricity is not considered part of the bioethanol plant but like a by-product of the chain.

Basing on these premises, the allocation on bioethanol is 89% and the rest is by-products. Inserting the data obtained from the sweet sorghum cultivation in Italy and from the elaborated model in terms of energy input and outputs of the entire chain, the final results were obtained.

The used tool is structured in order to work in already prepared pathways inserting own data to finally get values for emissions deriving from cultivation phase \( (e_{\text{ec}}) \), from transport and distribution phase \( (e_{\text{ig}}) \), from processing phase \( (e_{\text{p}}) \), from eventual land use change \( (e) \), from improved agriculture management \( (e_{\text{esca}}) \) or carbon dioxide capture and replacement \( (e_{\text{ccr}}) \) or carbon dioxide capture and geological storage \( (e_{\text{ccs}}) \) and automatically it is possible to obtain the GHGs emissions saving expressed in percentage and the grams of \( CO_2 \) emitted per megajoule of bioethanol produced.

For adapting the considered model, the starting point is the sheet of bioethanol from sugarcane because this is a model which process a biomass that produces simple fermentable sugars like sweet sorghum.

# 9.2 Case study: the development of the EU model in the industrial area of Thessaloniki in Greece

## 9.2.1 Specific assumptions

The chain model to process sweet sorghum as sole feedstock in a plant of capacity 10,000 t/year (as anhydrous bioethanol) is applied in the following case.

The biomass yield in fresh and dry basis, as well as the juice and total sugar yields used in this case study are in accordance to the results of a pilot case study conducted in Northern Greece by the Technological Institute of Thessaloniki. These values are presented in Table 42.

From the 4 sweet sorghum cultivars that were tested in the 2 year study conducted in Northern Greece, one cultivar and more specifically the “Urja” cultivar had the greatest theoretical bioethanol yield.

According to the yields of the “Urja: cultivar, the agricultural land assumed to be cul-

<table>
<thead>
<tr>
<th>Industrial area of Thessaloniki, Greece</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climatic characteristics</td>
</tr>
<tr>
<td>Soil type</td>
</tr>
<tr>
<td>Rainfall in the growth period</td>
</tr>
<tr>
<td>Sowing time</td>
</tr>
<tr>
<td>Harvesting time</td>
</tr>
<tr>
<td>Crop diversification</td>
</tr>
<tr>
<td>Farm structure</td>
</tr>
</tbody>
</table>

Table 41: main characteristics of the geographic area considered in the case study
ivated for the needs of the EU model, applied in Greece, is 1,660 hectares and the range of supplying the feedstock is an area at a distance of 20 km from the bioethanol plant. The agricultural fields are located next to the Industrial Area of Thessaloniki where the plant will be hosted. The members of the Agricultural Cooperative of Halastra own an agricultural surface of 6,000 hectares.

In this scenario, according to the EU model the harvesting requires 6 parallel yards; each one of them has 6 mower-shredder-charger machines and 24 farm tractors.

In this climate the duration of the harvesting period can be up to 40 days, if short cycle varieties and long cycle ones are cultivated at the same time in different fields of the considered agricultural surface.

The main details of the agricultural phase are reported in Table 43.

**Fertilisation:** 2 days before sorghum planting, 130 kgN/ha, as ammonium sulphate \([(NH_4)_2SO_4] \) 50 kgP/ha as super phosphate \([Ca(H_2PO_4)_2] \) and 65 kgK/ha as potassium sulphate \((K_2SO_4) \) are broadcast applied.

**Biomass:** the plant’s goal is to produce 10,000 t (12,649,200 liters) of bioethanol per year by using sweet sorghum as feedstock. Fresh biomass’s efficiency is estimated at 97.3 t/ha, the agricultural surface is estimated at 1,660 ha and bioethanol efficiency is estimated at 6 t/ha or 7.6 m³/ha. In order to produce 10,000 t of bioethanol 161,518 t of fresh biomass are needed. As regards the costs, there is no available data about the price of sweet sorghum, as a feedstock for bioethanol production in Greece, because so far there are only pilot crops and no regular production. According to the EU model the agricultural costs are estimated at 16-

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Urja</td>
<td>97.3</td>
<td>33.5</td>
<td>34.4</td>
<td>14.4</td>
<td>3.86</td>
<td>7620</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 42: fresh biomass yields, dry biomass yields, juice yields, degree Brix of juice, total sugar yield and theoretical bioethanol yield of “Urja” cultivar grown in soil salinity of 3.2 dSm⁻¹ and received irrigation of 210 mm

<table>
<thead>
<tr>
<th>Fertilisation</th>
<th>130 kgN/ha</th>
<th>50 kgP/ha</th>
<th>65 kgK/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>210 mm</td>
<td>(supplemented with 142-261 mm of rainfall during growth)</td>
<td></td>
</tr>
<tr>
<td>Moisture content</td>
<td>65.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anhydrous bioethanol yield</td>
<td>6 t/ha</td>
<td>7.6 m³/ha</td>
<td>164.8 GJ/ha</td>
</tr>
<tr>
<td>Bioethanol production</td>
<td>10,000 t/year</td>
<td>12,649 m³/year</td>
<td></td>
</tr>
<tr>
<td>Processed fresh biomass</td>
<td>161,518 t/year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processed dry biomass</td>
<td>55,610 t/year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural Surface</td>
<td>1,660 ha</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 43: detailed characteristics of the cultivation of sweet sorghum and bioethanol production in the case study
18 €/t wb, while the final net income for the farmers is estimated at 12-14 €/t wb.

**Anhydrous bioethanol yield:** for the calculation of the theoretical bioethanol production from sweet sorghum fresh biomass, the equations reported by Sakellariou-Makrantonaki *et al.* (2007) and Zhao *et al.* (2009) were used as follows:

\[ \text{total bioethanol yield [l/ha]} = \text{total sugar content [%]} \times \text{fresh biomass [t/ha]} \times 6.5 \times 0.85 \times \left( \frac{1.00}{0.79} \right) \]

The processing is carried out in accordance with the guidelines reported in the previous part.

As regards with the exploitation of the by-products, the electricity is sold to the grid and heat is used for the self-consumption of the plant.

The most important factor for the success of such a project is the suitable location for the bioethanol plant to be installed. However, the possible alternative sites can be various. The most optimal solution would be the result of a methodology based on a systematic research, analysis and evaluation of specific alternatives.

**Basic requirements for site collection**

The possible sites where the plant should be located must meet the following requirements:

- availability of human resources
- cost for land purchase
- easy supply of raw materials
- sufficient environmental conditions
- availability of transport facilities
- proximity to markets
- availability of auxiliary materials and services of public utilities
- acceptance by the local community
- adequate financial, administrative and social infrastructure
- special services and facilities provided by the development law n. 2011/3908.

The starting point for a preliminary selection or rejection of some sites is the location of raw materials. The bioethanol plant should be located near the cultivated land of sweet sorghum.

The second point is the existence of an industrial park in the area. The industrial parks provide specific advantages to the companies located there such as integrated infrastructure, organized industrial activities, infrastructures for water supply, for energy supply, communication network (telephone, internet services), wastewater treatment, road networks.

Furthermore, the installation of a plant inside an industrial park provides the following technical and business advantages to the future investors:

- concession terms of layout
- developed network of technical infrastructure
- added-value services (natural gas, broadband network, fire station)
• transport access
• easy installation with fewer bureaucratic requirements
• preferential subsidy through development law.

**Industrial Park of Thessaloniki**

The Industrial Park of Thessaloniki is located northwest of the city (18 km) at the area of Sindos, and complies with the above requirements. The Industrial Park has a total surface area of 395 hectares covering 12 blocks with streets and common use areas, whereas approximately 187 hectares of building plots are currently available. Private-use vehicles or other heavy-duty vehicles can pass through the VIPATHE via the road network that is currently being built between the 12 blocks. Also, in order to facilitate the companies that are to be co-housed in the park, there is a railway platform linking the park with the railway lines leading to Thessaloniki, Athens and the urban centers of northern and north-eastern Greece, Bulgaria and FYROM.

Characteristics of the industrial Park of Thessaloniki

1. **Availability of human resources**
   
   The Regional unit of Thessaloniki has a population of 1,104,460\(^{107}\). The unemployment rate in the region of Central Macedonia is 18.8\(^{108}\%\).

2. **Cost of site**
   
   The cost for land purchase amounts to 160 €/m\(^2\)\(^{109}\).

3. **Easy supply of raw materials**
   
   The total cultivable land in the Regional unit of Thessaloniki is around to 412,747 hectares\(^{110}\).

4. **Sufficient environmental conditions**
   
   The average temperature in Thessaloniki is 5.2 °C in January and 26.6 °C in July. The average rainfall for the same months is 36.8 mm and 23.9 mm, respectively.

5. **Availability of transportation facilities**
   
   The Industrial Park of Thessaloniki is located near the highway Athens-Thessaloniki and the Egnatia Road and the refining oil industry “HELLENIC PETROLEUM S.A". The railway, the airport, the port and the bus line are close to the area as well.

6. **Proximity to markets**
   
   The Industrial Park is on the verge of the second largest market in Greece, Thessaloniki, and is facilitated by the port of Thessaloniki.

![Figure 29: Industrial Park of Thessaloniki for the potential location of the plant\(^{106}\)](image)
7. **Availability of auxiliary materials and services of public utility**

The Industrial Park has water supply, waste treatment, pollution control laboratory. It also offers telephone and electricity networks, broadband communications, fire service and connection to the natural gas network.

8. **Adequate financial, administrative and social infrastructures**

The Industrial Park has an administration and management department, while the city of Thessaloniki offers all the necessary administrative, economic and social services.

9. **Special services and facilities provided by the development law 2011/3908**

For the Industrial Area of Thessaloniki the development law provides 35% subsidy or leasing subsidy or grant for the employment cost.

9.2.2 **Economic analysis**

The main costs considered in the production line of bioethanol from sweet sorghum are according to the model 1 and are summarised in Table 44.

The investment costs is estimated at 30 million €, including buildings, equipment, extraordinary maintenance, overheads (5%), technical costs (5%), unforeseen expenses (4%) land acquisition, eventual licenses and patents are not included. The operative costs include the purchase of chemicals, the water management, disposal of ashes, biomass transportation, insurance and other cost categories.

Concerning the incomes, the price of bioethanol depends on the energy market, especially on the price of oil, and the considered range is depended on the oil prices. The values are reported as average values in Table 45.

As regards with the incomes from the electricity selling, the FIT rate, in Greece, is ranged from 0.15-0.20 €/KWh and these Values are guaranteed for 20 years. More specifically:

- 200 €/MWh is the electricity selling for power installed inferior to 1 MW
- 175 €/MWh is the electricity selling for power installed from 1 MW to 5 MW
- 150 €/MWh is the electricity selling for power installed higher than 5 MW.

As regards with the number of jobs, it is estimated that 14 people will be working each hour in the bioethanol plant (Table 46).

---

<table>
<thead>
<tr>
<th>Biomass</th>
<th>~160,000 t/year x 30€/t=4,800,000€/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost</td>
<td>30 million €</td>
</tr>
<tr>
<td>• Operative costs</td>
<td>1,220,000 €/year</td>
</tr>
<tr>
<td>• O&amp;M</td>
<td>2,690,000 €/year</td>
</tr>
<tr>
<td>Other</td>
<td>1,220,000 €/year</td>
</tr>
</tbody>
</table>

Table 44: main costs included in the economic analysis of the case study

---

(1) Such schemes pay renewable energy producers a set rate (tariff) for each unit of electricity fed into the grid, and generally oblige power companies to purchase all electricity from eligible producers in their service area over a long period of time.
9.2.3 GHGs emissions saving

Bioethanol production facility, as any industrial process, faces a big challenge. This challenge is to protect the environment not only during the period of construction, but during the operation as well. As a result, one of the main goals of the plant is to decrease GHGs emissions, throughout the LCA.

**Cultivation phase**

The emissions deriving from cultivation section include all the agronomic parts of the chain, as follows:

1. the input data of the biomass yield in the area western of Thessaloniki’s Regional District (Northern Greece) is 97.3 t/ha wb (moisture 65.6%), specifically expressed in 97,300 kg/ha/year, and the correspondent energetic output of 582,399 MJ_{sorghum}/ha/year is automatically calculated;

2. the energy consumption has been calculated considering the sum of primary energy, fuels and lubricants for the machineries for cultivation in the specific case study: it corresponds to 5,563 MJ/ha/year;

3. the agrochemicals inputs have been reported as actually used in the case study for sorghum cultivation: N 130 kg/ha/year, K\_2O 50 kg/ha/year, P\_2O\_5 65 kg/ha/year. Pesticides and herbicides have been calculated as 2 kg/ha/year;

4. the vinasse deriving from the distillation and rectification unit is not considered to be utilised as fertiliser because it is used in anaerobic digestion section for biogas production. Otherwise, the residual digested matter after biogas production is...
considered as source of organic fertilisation for sorghum cultivation. The amount has been calculated considering the production of digested matter which is 60,621.5 t/year to share in 1,660 ha, and the resulting amount is 36,519 kg/ha/year;

5. the seeding material used in the case study is 10 kg/ha/year;

6. the field N$_2$O emissions have been calculated using the specific part of “N$_2$O emissions IPCC”. The biomass yield reported is 97,300 kg/ha/year wb (moisture 65.6%). The land use is from arable to arable land. In the direct N$_2$O emissions from managed soils the inputs are 130 kg N/ha/year of synthetic fertiliser. The indirect N$_2$O emissions are automatically calculated. The N$_2$O resulted emissions are 3.51 kg N$_2$O/ha/year.

The emissions from cultivation phase correspond to 15.09 gCO$_2$/MJ$_{bioethanol}$

The digested matter is transferred to the fields for the organic fertilisation. The resulting amount is 0.37 gCO2/MJ$_{bioethanol}$ which is summed to the previous number.

With the allocation the emissions correspond to 13.75 gCO2/MJ$_{bioethanol}$ as it is shown in Table 47.

<table>
<thead>
<tr>
<th>Cultivation phase</th>
<th>kg/ha/year</th>
<th>MJ$_{sorghum}$/ha/year</th>
<th>MJ/ha/year</th>
<th>gCO2/MJ$_{bioethanol}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass yield</td>
<td>97,300</td>
<td>582,399</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>-</td>
<td>-</td>
<td>5,563</td>
<td>3.02</td>
</tr>
<tr>
<td>N</td>
<td>130</td>
<td>-</td>
<td>-</td>
<td>4.74</td>
</tr>
<tr>
<td>K</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>0.23</td>
</tr>
<tr>
<td>P</td>
<td>65</td>
<td>-</td>
<td>-</td>
<td>0.52</td>
</tr>
<tr>
<td>Pesticides</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>0.14</td>
</tr>
<tr>
<td>Digested matter</td>
<td>36,519</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Seeding material</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Field N$_2$O emissions</td>
<td>3.51</td>
<td>-</td>
<td>-</td>
<td>6.44</td>
</tr>
<tr>
<td>Transport of digested matter</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.37</td>
</tr>
<tr>
<td>Total without allocation</td>
<td></td>
<td></td>
<td></td>
<td>15.46 gCO2/MJ$_{bioethanol}$</td>
</tr>
<tr>
<td>Total with allocation*</td>
<td></td>
<td></td>
<td></td>
<td>13.75 gCO2/MJ$_{bioethanol}$</td>
</tr>
</tbody>
</table>

*allocation factor 89%

Table 47: GHGs emissions from the cultivation phase

**Transport and distribution phases**

For the transport phase, the quantity of product in mega joule is automatically calculated in 582,399 MJ$_{sorghum}$/ha/year. The transport per truck for dry product with Diesel fuel is considered for the average value of 20 km. The partial value for emissions from this transport phase is 1.46 gCO2/MJ$_{bioethanol}$ but this value must be summed with the transport of bioethanol from the plant to depot and then to filling stations. For this part of the transport the allocation factor must be considered (89%), so the emissions are 0.88 gCO2/MJ$_{bioethanol}$.

For Transport (etd) the final value is 1.77 gCO2/MJ$_{bioethanol}$ (Table 48).

**Processing phase**

Based on the data of the case study 0.277 MJ$_{bioethanol}$/MJ$_{sorghum}$ is produced.

In the sweet sorghum based model the large excess of electricity produced by
CHP plant plus the biogas combustion is sold to the grid. The electricity taken from CHP plant for the bioethanol production corresponds to 0.108 MJ/MJbioethanol. Since electricity is produced in a larger amount than the requirement of the plant, this is not really a demand but a reduced electricity output. The output of electricity from the steam production is credited by the electricity from bagasse burnt in CHP plant with steam turbine for power generation. As a consequence, also the electricity demand in the bioethanol plant is considered to be electricity from bagasse burnt in CHP plant to acknowledge for the fact that in practice this is not a demand, but a reduced electricity output.

In the considered case study the total production (output) of electricity is 43,240 MWh (155,664 GJ) obtained from bagasse burning, biogas and concentration section. Subtracting the amount relative to by-products (8,996 MWh) the electricity

<table>
<thead>
<tr>
<th>Table 48: GHGs emissions from the transport and distribution phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHGs emissions transport and distribution</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Transport of harvested sweet sorghum</td>
</tr>
<tr>
<td>Transport of bioethanol from plant</td>
</tr>
<tr>
<td>Energy consumption depot</td>
</tr>
<tr>
<td>Filling station</td>
</tr>
<tr>
<td>Total without allocation</td>
</tr>
<tr>
<td>Total with allocation*</td>
</tr>
</tbody>
</table>

*allocation factor 89 %

Table 49: GHGs emissions from the processing phase

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield bioethanol</td>
</tr>
<tr>
<td>By-products</td>
</tr>
<tr>
<td>Electricity taken from CHP</td>
</tr>
<tr>
<td>Steam from CHP</td>
</tr>
<tr>
<td>Electricity generation (total)</td>
</tr>
<tr>
<td>Electricity bagasse Steam Turbine*</td>
</tr>
<tr>
<td>Chemicals</td>
</tr>
<tr>
<td>Total without allocation</td>
</tr>
<tr>
<td>Total with allocation***</td>
</tr>
</tbody>
</table>

* surplus electricity, credit is calculated following RED Annex V C.16
** electricity output, so it is negative
***allocation factor 89 %
produced just in the CHP with bagasse is 34,244 MWh (123,278 GJ), correspondent to -0.454 MJ/MJ\textsubscript{bioethanol} on an annual basis. Subtracting the electrical consumptions of the plant, the obtained value is -0.346 MJ/MJ\textsubscript{bioethanol}; this is the surplus of electricity and the credit is calculated following RED Annex V, C.16.

The thermal energy produced in form of heat is completely re-used in the plant for internal needs.

In the part relative to the chemicals used in the plant, the values are the same of sugarcane bioethanol: chemicals used in the production processes and lubricants for the machineries.

The emissions from the processing (e\textsubscript{p}) is -1.12 gCO\textsubscript{2}/MJ\textsubscript{bioethanol}. The details are summarised in Table 49.

**Land use change and improved agricultural management**

The LUC, the improved agricultural management, the CO\textsubscript{2} capture and replacement and for CO\textsubscript{2} capture and geological storage, are not considered.

**GHGs emission saving in the case study**

The final value of emissions per mega joule of bioethanol obtained from sweet sorghum corresponds to 14.66 gCO\textsubscript{2}/MJ\textsubscript{bioethanol}. The allocated result corresponds to 13.04 gCO\textsubscript{2}/MJ\textsubscript{bioethanol}

The emission reduction resulting from the calculation foreseen in the RED corresponds to 82.5 %.

**9.3 Case study: the development of the EU model in Andalusia in Spain**

**9.3.1 Specific assumptions**

The chain model to process sweet sorghum as sole feedstock in a plant of capacity 10,000 t/year (as anhydrous bioethanol) is applied in the case study contextualised to the Jédula (Cádiz) in South of Spain (Andalusia). In fact the Ministry of industry, tourism and trade of Spain, in compliance of EU instructions, has just released a

<table>
<thead>
<tr>
<th>Jédula (Cadiz), South Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climatic characteristics</td>
</tr>
<tr>
<td>Rainfall in the growth period</td>
</tr>
<tr>
<td>Sowing time</td>
</tr>
<tr>
<td>Harvesting time</td>
</tr>
<tr>
<td>Crop diversification</td>
</tr>
<tr>
<td>Farm structure</td>
</tr>
</tbody>
</table>

Table 50: main characteristics of the geographic area considered in the case study
The production of 1st generation bioethanol is carried out in accordance with the guidelines reported in the previous part. The utilised continuous diffuser has an efficiency of 97%; consequently the sugar concentration is 12% in the juice and 5% db in the bagasse. Bagasse has residual moisture than can vary between 31% and 50%. As regards with the concentration unit, the continuous supply of the fermentation reactors is planned concentrating at 80% the most of the sugar juice (54.5% of the total amount) and at 45% only a 27.3% of the total amount,
and without any concentration or a reduced concentration (15-18%) and used directly to produce bioethanol the 18.2%. The following fermentation of the newly diluted sugar juice is carried out with a batch process. The applied efficiency of the alcoholic fermentation is 90% of the theoretical one.

The obtained anhydrous bioethanol has a purity of 99.7% w/w and it is suitable to produce bio-ETBE or for blending with petrol.

Concerning the by-products exploitation, wet bagasse is stored and dried up to 10-20% immediately before the burning in the CHP plant. During the storage a biomass loss of 5% is hypothesized (mainly sugars). The CHP plant is fitted out with a biomass burner, a steam generator and a steam turbine; its thermal efficiency is 0.90 and power efficiency is 0.29. Unlike the other units, this CHP plant works for 360 days per year. Biogas obtained from vinasse supplies a gas micro-turbine with electrical efficiency 34%.

In this case study, electricity is sold to the grid and heat is used for the self-consumption of the plant.

In Spain, there are incentives to the power generation from renewable energy, and specifically from biomass, with a price of 16.81 c€/kWh from biomass (when the cogeneration plant has more than 2 MW installed) if this bagasse is considered as an energy crop, and 11.38 c€/kWh if bagasse is considered as biomass waste from industrial plants.

Considering the amount of 77,310 tonnes per year of bagasse, the power installation can be 10 MWe.

Heat is able to cover the thermal consumption of the plant. The highest consumptions concern the following units: the concentration of sugar juice (only during the harvesting period), the distillation and rectification units, the drying of the bagasse. In this case study the selling of heat through a district heating network is not considered, because there is a reasonable difficulty in the considered area in finding users.

Apart these assumptions, the case study apply the contents of the EU model 1.

### 9.3.2 Economic analysis

The main costs and incomes considered in the economic analysis are summarised in Table 52.

<table>
<thead>
<tr>
<th>Economic analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Investment cost</td>
<td>30 million €</td>
</tr>
<tr>
<td>Operative costs</td>
<td></td>
</tr>
<tr>
<td>Biomass 29-34 €/t (34 €/t db with a 38% of sugar in the stalk db)</td>
<td>6.23-7.30 million €/year</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>2.69 million €/year</td>
</tr>
<tr>
<td>Other</td>
<td>1.22 million €/year</td>
</tr>
<tr>
<td><strong>Incomes</strong></td>
<td></td>
</tr>
<tr>
<td>Final products</td>
<td></td>
</tr>
<tr>
<td>Bioethanol price 450-800 €/m³</td>
<td>5.63-10.00 million €/year</td>
</tr>
<tr>
<td>Supported electricity price from biomass 16.81 – 11.38 c€/kWh (10 MWe installed has a production of 86,400 MWh per year, 360 days and 24 h per day)</td>
<td>14.52 – 9.83 million €/year</td>
</tr>
</tbody>
</table>

Table 52: main costs and incomes included in the economic analysis of the case study
The investment costs include buildings, equipment, extraordinary maintenance, overheads (5%), technical costs (5%), unforeseen expenses (4%); land acquisition, eventual licenses and patents are not included.

In the operative costs the purchase of chemicals, the water management (i.e. discharge of waste water from the concentration unit, purchase of drinking water for the dilution of syrup), the disposal of ashes, the biomass moving and the insurance are included in the item named “Other”.

The price of biomass and the values for the incomes are reported as range.

The adequate reward of farmers as biomass suppliers is the prerequisite for the development of the chain. Consequently the quantification of the price of biomass requires a very precautionary approach. Assuming that in the considered area the agricultural costs are 16-18 €/t wb (correspondent to 1,040-1,170 €/ha, included the transport to the plant with an average distance of 10 km), the affordability threshold is estimated at 30 €/t. In fact in worse conditions other crops become more competitive than sweet sorghum and then the security of supply becomes critical. Depending on the concentration of sugar in the sweet sorghum stalks, the price of the biomass can vary, increasing this price per tonne if the amount of sugar is higher.

The price of bioethanol depends on the international energy market, considering the international price of bioethanol from Brazil, the US or India. Considering this price and the transport cost to Europe or the duty in Europe for the external bioethanol, the final price must have a maximum value of 80-85 c€/l. On the other hand, the minimum price of bioethanol can be fixed on 45 c€/l. This value can be evaluated with the data of production cost in Brazil, that is about 30 c€/l.

Considering the cost evaluation of the bioethanol production process, the objective of the plant manager must be the use of the maximum amount of sweet sorghum biomass for power generation.

Considering the information showed on Table 53, the range of total cost is 10.14-11.21 million €/year and the range of incomes is 15.46 – 24.52 million €/year. If the total investment cost is fixed on 30 million €, the payback can vary between 2.5 years (the best case) and 7.5 years (the worst case).

The evaluation has been made considering the crop area of Jédula (Cádiz) in Spain, where the sweet sorghum yield is 31 t/ha db.

In Figure 30, the production yield in Andalusia is indicated.

The production of sweet sorghum in Andalusia has a very good result only with irrigation. The irrigation data obtained for this crop in Andalusia can vary between 4.0 and 4.3 m³/ha. Thus, if the water use efficiency for this crop is 0.16-0.27 m³/kg db, the total amount of water needed for the crop (with a production of 31 t/ha) is 4.96-8.37 m³/ha, that is the sum of irrigation and rainfall.

With the information before mentioned, the calcula-
tion of GHG emissions and energy consumptions has been made, obtaining the saving on these aspects due to the use of sweet sorghum as feedstock for the production of bioethanol.

**Transport and distribution phases**
The calculation of transport cost and consumption of the raw material transport have been executed, considering the type of roads and distance between the crops and the production plant.

The Figure 31 shows the positioning of the production plant and the crops area that can be used for the bioethanol production.

Considering these aspects, the energy consumption and the GHG emissions calculation have been executed and showed in Table 55.
Processing phase

In the processing phase, the evaluation of the production process has been done considering the standard production process described before.

The inputs and outputs of the production process are indicated in Table 56. This information allows the subsequent calculation of the GHGs emissions and the energy balance of the bioethanol production process.

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption</td>
<td>0</td>
</tr>
<tr>
<td>Power</td>
<td>0</td>
</tr>
<tr>
<td>Thermal Energy</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 58: energy balance in the bioethanol production process from sweet sorghum (as MJ/M\textsubscript{bioethanol})

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption</td>
<td>0</td>
</tr>
<tr>
<td>Power</td>
<td>0</td>
</tr>
<tr>
<td>Thermal Energy</td>
<td>0</td>
</tr>
<tr>
<td>e\textsubscript{p}</td>
<td>0.4</td>
</tr>
<tr>
<td>e\textsubscript{ee}</td>
<td>0</td>
</tr>
<tr>
<td>e\textsubscript{CCR}</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 57: GHGs emissions in the bioethanol production process from sweet sorghum (as gCO\textsubscript{2eq}/M\textsubscript{bioethanol})

9.3.3 GHGs emission saving in the case study

After the evaluation of all the information referred to the bioethanol production process from sweet sorghum in Jédula, the most important results are the savings calculated due to the use of sweet sorghum as feedstock instead of fossil fuels. This aspect is very important and ensures the sustainability of the bioethanol production from sweet sorghum.

The specific results obtained in the bioethanol production from sweet sorghum are showed Table 59 and Table 60. The GHGs emissions saving of this case study corresponds to 79%.
<table>
<thead>
<tr>
<th>Crop</th>
<th>Energy consumption by agricultural steps</th>
<th>Energy consumption by transport steps</th>
<th>Energy consumption by bioethanol production</th>
<th>Total [MJ/MJ]</th>
<th>Saving [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet sorghum (irrigation) in Andalusia</td>
<td>0.07</td>
<td>0.021</td>
<td>0.01</td>
<td>0.10</td>
<td>92</td>
</tr>
</tbody>
</table>

Table 59: fossil energy consumption of the bioethanol production in Spain (Jédula) (as MJf/MJbioethanol)<sup>121</sup>

<table>
<thead>
<tr>
<th>Crop</th>
<th>Emissions by agricultural steps $e_{ec}$</th>
<th>Emissions by transport steps $e_{e}$</th>
<th>Emissions by bioethanol production $e_p$</th>
<th>CO$<em>2$ captured $e</em>{ccr}$</th>
<th>Total $[gCO_{2eq}/MJ]$</th>
<th>Saving [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet sorghum (irrigation) in Andalusia</td>
<td>14.3</td>
<td>2.3</td>
<td>0.4</td>
<td>-</td>
<td>17.2</td>
<td>79</td>
</tr>
</tbody>
</table>

Table 60: GHGs emissions in the bioethanol production in Spain (Jédula) (as gCO$_{2eq}$/MJbioethanol)<sup>122</sup>
10. THE EU MODEL 2: SWEET SORGHUM AND SUGAR BEET AS FEEDSTOCK OF THE PLANT

This model is aimed to develop in the EU a chain based on sweet sorghum and another bioethanol crop as feedstock for the same decentralised small-medium plant. This model has been studied as alternative to the first one, because the model 1 is penalised by the dependence from just one feedstock. Furthermore, the model 2 has the advantage to allow to process mainly fresh raw material and consequently to minimize the concentration of the sugar juice. In fact the short number of days of the harvesting period obliges to make a high concentration of the sugar juice to maintain the production process of the bioethanol plant (fermentation, distillation and dehydration) during almost all the year (11 months per year). On the contrary using also another fresh biomass the required concentration level can be significantly reduced. The disadvantage of the model 2 is due to the necessity that in one area two bioethanol crops must be cultivated in different period of the year. This condition can be satisfied or not in different regions.

10.1 Case study: the development of the EU model 2 in Andalusia in Spain

In order to explain this model for the EU, the guidelines described in previous chapter 7 are applied to an exemplifying plant with capacity as anhydrous bioethanol of 10,000 t/year.

Specifically the case study is contextualised in Jédula (Spain, Andalusia), and sugar beet is considered as complementary to sweet sorghum.

Sugar beet in Andalusia has a harvesting period from June to July and the storage of the sugar beet can be done during one month without losing more than 3-4% of sugars. Thus, the bioethanol production plant can work with fresh raw material from June to November, combining sugar beet during June, July and August, and early sweet sorghum on September, and standard sweet sorghum on October and November.

From December to April (5 months) the bioethanol plant works with concentrated sugar juice. In the month of May the maintenance of the plant and the equipment is carried out.

10.1.1 Specific assumptions

Agronomical phase

The same conditions in Jédula indicated in Table 50 are taken into consideration. The production of sugar beet can vary between 80,000 – 120,000 kg/ha with irrigation. Considering the percentage of sugar per kilogram of sugar beet, the variation can be between 13% and 16% of the fresh samples. Usually, the amount of sugar can be fixed on 14%.

This amount of sugar per kilogram and the productivity of sugar beet per hectare is indicating a variation of 6,600 – 10,000 litres per hectare of bioethanol.

The calculations of the model have been done considering a bioethanol plant with a capacity of 12,500 m³/year (i.e. 10,000 t/year). Thus, if the sugar beet is the raw material for three months per year, the amount of bioethanol from sugar beet must
be approximately 3,500 m³/year. This production requires from 350 to 525 hectares of sugar beet, depending on their productivity.

**Logistics**

The logistic system of this model is similar for both raw materials as regard with the transport from the fields to the production plant.

An important difference between the 2 crops is the time needed from the harvest to the process.

Apart from the density of the crops, the type of machinery to make the harvest and so on, the main difference is that the storage of the sweet sorghum is not possible due to the sugar loss and the beginning of fermentation after 7-8 hours, but, on the other hand, in the case of sugar beet, the storage can be done in the field or in the production plant during one month. Apart from this, the maintenance of the sugar beet in the fields without harvesting it is possible without losing the sugars.

Thus, sugar beet can be used as feedstock increasing the time between the harvest and the process. This allows making a better structuring of the transport from the fields to the production plant and reducing the transport cost using bigger trucks and trailers.

**Processing**

The production process must be adapted to the use of sugar beet and sweet sorghum as feedstock. This is not an important problem, due to the fact that the types of sugar stored in the sugar beet and in the stalks of sweet sorghum are sucrose, glucose and fructose. Thus, the fermentation, distillation and dehydration are similar.

The main difference between the use of sugar beet or sweet sorghum is on the first step of the process, during the cleaning of the raw material, cutting and sugar extraction.

In this model the incorporation of a cleaning line is necessary to eliminate sludge and stones from the sugar beet before the cutting step. In the case of sweet sorghum, there is not a cleaning step, and after the reception of the stalks, these are shredded before the extraction.

The extraction process must be done with a continuous diffuser to ensure the best yield on the extraction process and the use of the same equipment for extracting from sweet sorghum and sugar beet. On the contrary the rolling mill can not be used in the extraction of sugar from sugar beet.

After the extraction, the other steps of the process are similar regardless the type of raw material.

10.1.2 Economic analysis

The economic analysis can be similar to the analysis indicated in the evaluation of the model 1 in the case study in Spain.

10.1.3 GHGs emission saving

The calculation of the GHGs emissions saving has been done considering 2 alternatives. The first is considering the use of natural gas as fuel to obtain the energy required by the production plant. The second option is the use of biomass as fuel in the boiler. This
biomass could be the bagasse obtained from sweet sorghum sugar extraction phase. This means that the biomass must be stored during all the year to be used regardless the raw material, sweet sorghum or sugar beet, that has no biomass on the crop.

If the production process uses natural gas as fuel on the production plant, the emissions reduction is 57% by the use of sugar beet as raw material for producing bioethanol. Then, considering the amount of hectares of sugar beet, the final calculation for all the process applies a 57% of reduction for a 27.3% of the total production and a 79% of reduction for the 72.7% produced from sweet sorghum.

The average of the total production process, considering this alternative, is 73% of reduction of the GHGs emissions using sugar beet and sweet sorghum combined. This calculation has been done using natural gas as fuel in the production plant during the bioethanol production from sugar beet and bagasse during the bioethanol production from sweet sorghum.

The second option for the bioethanol production from sugar beet and sweet sorghum is the use of biomass for all the year and for all the bioethanol production regardless the type of raw material.

If the fuel used on the bioethanol from sugar beet is biomass (i.e. bagasse from

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**Figure 32: GHGs emissions of bioethanol obtained from sugar beet using natural gas as fuel**

**Figure 33: GHGs emissions of bioethanol obtained from sugar beet using biomass as fuel**
the sweet sorghum of the previous production period), the GHGs emissions from the bioethanol production process using sugar beet as raw material are lower. The emissions saving with sugar beet as raw material is 83%.

Thus, if the amount of bioethanol produced from sugar beet is a 27.3% from the total production, and the emissions reduction with sweet sorghum is 79% for 72.7% of the total capacity of the plant, the average of the emissions reduction for the total process is 80%.

10.1.4 Considerations of the EU model 2

The main characteristic of the sugar beet is that this crop is not going to produce biomass to be used on the boiler. Thus, there are going to be two alternatives, the use of natural gas, that reduce the saving on the GHGs emissions, or the use of biomass from the sweet sorghum stored during all the year to provide energy to the plant during the bioethanol production from sugar beet. The second option is going to ensure a better result with more savings on the GHGs emissions and less production cost.

On the other hand, the combination of sweet sorghum and sugar beet forces to the modification of the production plant, including a new line for cleaning the sugar beet before the process and including a storage area for the sugar beet. The increasing on the plant cost due to these new steps is going to be compensated by the reduction on the scale of the extraction and concentration unit, because with sweet sorghum, the extraction of sugar juice during two months must be enough to cover the needs of all the year on the bioethanol plant. On the other hand, the use of sugar beet and sweet sorghum allows working with fresh raw material during 5 or 6 months per year. Thus the extraction scale can be reduced. The extraction unit must produce during 5 or 6 months the sugar juice for all the year (instead of 2 month to make the same work).

Apart from the reduction on the extraction and concentration equipment scale, the energy consumption on the extraction and concentration units is going to be lower. Thus, this energy can be used (biomass) to cover the needs of the production from sugar beet.
11. TRANSFERABILITY

The possibility of transferring the model for bioethanol and bioenergy production using sweet sorghum depends on the specific situation of each considered EU country. In particular, suitable countries in EU for sweet sorghum cultivation besides Italy, Spain and Greece, are Bulgaria, Romania, Hungary, France, Portugal and Croatia.

The most important factors for the diffusion of the sweet sorghum based model for bioethanol and bioenergy production in these countries are the internal bioethanol production, the State incentives for biofuels production, the influence of bioethanol importation, the country’s policies on biofuels.

11.1 Bulgaria

Mandatory targets set by the RED indicates 16% share of RES on the final consumption of energy in 2020. At least 10% share of biofuels of final consumption of energy in transport in 2020.

Bulgaria has capacities for the production of 250,000 tons of biodiesel and 60,000 tons of bioethanol per year. According to Bulgaria’s economy, energy and tourism Ministry in 2009, 18,456 tons of biodiesel were manufactured in Bulgaria. Around 350 tons of this was sold to the domestic market, while the rest was exported. The production of biofuels is based on local raw materials which could contribute to improving the security of supplies. For Bulgaria, biofuels represent an alternative to petrol and diesel fuels which allows the dependency on the import of fuels to be reduced and contribute to the security of energy supplies. Bulgaria has a production capacity of around 240,000 tons but the only refinery, which produce biofuels in Burgas has stopped working in 2011. Due to high expectations and standards forced, the owner had to suspend the refinery. Its annual production was about 400 tons.

In accordance with ZVAEIB (in force since 2007; last amended by the ZVAEIB: 1st March 2010), by Decision under point 2 of Protocol Nº 43 approved at a meeting of the Council of Ministers of 15th November 2007, a National long-Term program for the promotion of the use of biofuels in transport in the time period 2008-2020 was adopted. The national indicative targets for the use of biofuels were determined on the basis of an analysis which reflects the actual potential for the cultivation of energy crops in Bulgaria. That analysis takes into account the information about existing plants and notified future plants expected to be commissioned. In determining the national indicative targets, the current condition and future development of the use of petrol and diesel fuels in the transport sector in the country have also been taken into consideration. The following national indicative targets for the use of biofuels in transport have been set like 8.0% in 2015 and 10.0% in 2020.

As a measure to reduce fuel prices, the parliament voted in 2011 in the new law on RES to delay the mixing of 5% diesel with bio-components by the end of the year.
To reduce diesel prices, the Government postponed by six months the European diesel requirement is 5% bio-components. This affected seriously the producers of biodiesel. Due to market uncertainty, farmers in 2012 are unlikely to sow energy crops. The National association of biofuels in Bulgaria calculated that the removal of bio-components in diesel will reduce the final price of transportation fuels. It will directly affect 250 people working in the industry, and about 1,000 people whose business is related to biofuels.

In 2011 a deferral for a further 3 years for mandatory blending of petrol with bioethanol was adopted. The requirement of bioethanol admixture, rather than come into force in March 2011, has been postponed until 2014.

The ZVAEIB is the main national instrument laying down the general principles of the policy on the promotion of the production and use of biofuels in Bulgaria. The compulsory blending of biofuels with mineral oil derivatives takes place only in tax warehouses authorized in accordance with the excise duties and tax warehouses act. Biofuels may be used in the transport sector in pure form or as a blending component in mineral oil derivatives for the operation of internal combustion engines. Biofuels must comply with the technical and quality requirements for biofuels and their blends with mineral oil derivatives laid down in the ordinance on the quality requirements for liquid fuels, the conditions, procedure and method of their control and in the relevant standards. It was found that the statutory requirements relating to the compulsory blending of biofuels with mineral oil derivatives were not put into practice and that, thus, no progress was made towards the achievement of the national indicative target. The reasons for the non-compliance with the ZVAEIB as regards the compulsory biofuel component in conventional fuels are complex. The main reasons cited by stakeholders are given below:

- difficulties encountered in meeting the requirements of the EN 228 standard in the case of blends of bioethanol with petrol;
- no tax incentives implemented in practice for the placing on the market of pure biofuels and biofuel blends;
- lack of laboratories accredited to check the quality and composition of biofuels and to determine with sufficient accuracy the bio-component content in a given blend;
- the time needed by producers and importers of liquid fuels to implement the investment programs relating to the technical preparation of the distribution systems;
- problems encountered in exercising control over the quality of pure biofuels and of biofuel blends offered on the market as well as the non-imposition of penalties in the case of noncompliance with the statutory blending requirements.

NREAP indicates that in order to fulfill the national targets about 115 ktoe of biofuels will be consumed in 2015 and 205 ktoe of biofuels will be consumed in 2020.

11.2 Romania

National commitments in the “Strategy for the utilisation of renewable energy sources” (2007-2020) and “National energy strategy 2007-2020”: 11% of RES in primary energy consumption by 2010 and RES with a share of 15% on the total primary energy sources by 2015.
As regards the promotion of use of biofuels, the related set targets are the following:

- by the end of 2010, the percentage of use of biofuels of the total energy content of fuels used for transmission shall be of minimum 5.75%;
- by the end of 2020, the percentage of use of biofuels shall be of minimum 10%, provided that the new generations of biofuels are used.

In 2009 approximately 231,216 tons of biodiesel and bioethanol were used in Romania (148,606 tons of biodiesel and 82,610 tons of bioethanol), which gives a percentage of 4.1% calculated on the basis of the energy content of all types fuels used in transport. In Romania there are 10 major investments in bioethanol plants. In 2009 the decrease in crude oil prices made the production of biodiesel less profitable thus some companies put their production on hold. The production of biofuels is developing but it is not accompanied by the development of filling stations. Lack of users is also problematic, so the public awareness campaigns should be launched.

Fuel suppliers are introducing on the market only a blend of biofuels and conventional fuels - derived from mineral oils as follows: a) from 1st January 2011, petrol with a minimum 5% biofuel content by volume; b) from 1st January 2013, petrol with a minimum 7% biofuel content by volume; c) from 1st January 2017, petrol with a minimum 9% biofuel content by volume; e) from 1st January 2018, petrol with a minimum 10% biofuel content by volume.

A number of actions have been initiated in order to contribute to the promotion of use of biofuels and other renewable fuels. Within this context, it shall be mentioned the introduction in the provisions of the fiscal code of the excise exempt for energy products such as biofuels and other renewable fuels. The promotion of use of biofuels and other renewable fuels for transport constituted the subject of decree 2005/1844 supplemented by the decree 2007/456. The decision stipulates that, for the promotion of the use of biofuels and other renewable fuels in order to replace petrol and diesel fuel, the quantity of biofuels and other renewable fuels shall be of minimum 2%, calculated based on the energy content of all types of petrol and diesel fuel used for transport and introduced on the market by the Romania’s accession date to the EU and minimum 5.75%, calculated based on the energy content of all types of petrol and diesel fuel used for transport introduced on the market by 31st December 2010.

The Ministry of economy, trade and the business environment is responsible for implementing the “Qualitative and quantitative monitoring system for petrol and diesel” marketed in filling stations, as approved by the order 2004/742 of the Minister for economy and trade, the annex to which was replaced by the order 2006/58 of the Minster for economy and trade. In 2009 it checks were carried out to determine the FAME content of approximately 200 diesel samples and to determine the content of biofuels in petrol in approximately 100 petrol samples. In accordance with Government decision 456/2007, failure to place the mix of biofuels and conventional fuels on the market is punishable by a fine of 1,725 € to 3,455 €. For shares of biofuels mixed in derivates of mineral oils exceeding the limit value 5% for bioethanol, a specific labelling shall apply within marketing points.

The inclusion in the fiscal code of an exemption from the payment of excise duty
for energy products that fall under the category of biofuels and other renewable fuels. This provision forms the subject of article 201(l) of the law 2003/571 on the fiscal code, as amended by the law 2006/343. The implementing rules for the fiscal code are approved by Government decision 2008/1618. Financial assistance is granted to agricultural producers for the cultivation of sunflower, oilseed rape, soya and corn under the single area payments scheme and the payment scheme for energy crops.

The National programme for rural development 2007-2013 pays special attention to the issue related to use of RES. The document shows that the developing biofuel market has the necessary potential to change the current structure of agricultural crops. Romania has the potential to produce approximately 2 million tons of bioethanol and 400,000 tons of biodiesel. The further development of biofuels consumption in Romania has been envisaged in the NREAP: 363.3 ktoe in 2015 and 489.2 ktoe in 2020. In order to stimulate the agriculture and favour at the same time the agro-energy sector, the Romanian Minister of Agriculture has unveiled plans to impose financial penalties on landowners who are not using fields for agricultural purposes: approximately 95 € a year per each hectare of unused land. In fact, according to statistics, at the current time in Romania 1.3 million hectares of arable land (about 14% of the Romanian arable lands) are uncultivated. This intervention is justified by the economic losses due to this land abandonment (estimated in 300 million euros a year): in fact an increased agricultural production means cheaper products and more money for the state budget from taxes.

The main barriers to increase the agricultural yields in Romania appear the old age of the farmers and the migration towards the towns.

11.3 Hungary

In 2005 the Hungarian excise tax act was amended regarding the sale of biofuels. The amendment stipulated that from 1st July 2007 fuels with a 4.4% v/v bioethanol content must be sold in Hungary. It equally stipulated that from 1st January 2008 fuels with a 4.4% v/v biodiesel content will also be sold. Hungary’s stated 2010 biofuel objective was 5.75%, which is calculated in relation to energy content. In 2009 the share of biofuels in annual fuel consumption for transport was 3.75 %; the share of bioethanol in petrol was 3.10 % and the share of biodiesel in diesel was 4.11 %, calculated on the basis of energy content.

In 2009 approximately 217,750 tons of biodiesel and bioethanol were used in Hungary (139,350 tons of biodiesel and 78,400 tons of bioethanol), which gives a percentage of 3.75 % calculated on the basis of the energy content of all types of petrol and diesel used in transport. In 2010 there was an increase: 122,500 tons of bioethanol used.

The mandatory biofuel share must be achieved every month. On the basis of authorisation by law this proportion is regulated by Government decree 2009/138 of 30th June concerning the implementing rules for certain provisions promoting the use of biofuels in transport (i.e. Government decree 2009/138). If the required blending ratio is not respected and the registration and reporting obligations are not complied with the authority, the Government imposes a fine. This fine (based on the energy content of the missing biofuel and on the purchase price of biofuel)
is an appropriate incentive for distributors to comply with their obligations. From 1\textsuperscript{st} January 2008 was introduced a tax differentiation: in the case of the product E85 for fuel use containing bioethanol (minimum 70 \%-maximum 85 \%), under heading 3824 90 99 pursuant to the Hungarian standard in force no excise duty had to be paid on the bioethanol component even in 2009. Tax differentiation for biofuels ended as of 1\textsuperscript{st} July 2009. The intention behind the tax increase on fuels was to eliminate tax differentiation based on bio-content for petrol and diesel in order to avoid the prior approval by the EC, which is necessary if changing tax while applying tax differentiation. At the same time, a different incentive had to be introduced to promote the use of biofuels for transport. The relevant regulation was passed in the framework of the same legislative packet that eliminated tax differentiation, thus ensuring the entry into force of the new regulation on 1\textsuperscript{st} July 2009. May be refunded € 0.26/l on tax paid on biodiesel produced in biofuel tax warehouses authorised by the customs authorities.

**Bioethanol plants**

KEOP 4.6 was launched in 2009, providing support for setting up medium and large capacity bioethanol plants. The approved NREAP proposed a support framework of 19 million euros for 2009-2010. The maximum amount of aid may be 5.7 million € per bioethanol production plant, which may be increased by another amount for setting up a renewable energy block providing energy for bioethanol production.

Europe’s largest maize-processing bioethanol plant was opened in Szabadegyháza in Fejér County and, in addition to raw materials for the food industry, produces large amounts of bioethanol that has earned favourable environmental protection rating in the EU. Hungrana Kft.’s communication showed that the company spent around 100 million € on capacity building and is currently able to process 3,000 tons of raw materials a day, making it the largest maize-processing plant in Europe. Hungrana, which was created from the former spirit company, produces mainly starch, isosugar and alcohol from maize in its plant. The technological level of the company, which is 50-50 jointly owned by British-American Eaststarch and the Austrian AGRANA group, is in the forefront in Europe, but the capacity increase has made this Hungarian plant the most up to date in the sector in the EU. The company processes more than one million tons of maize a year and the plant which employs 285 employees made HUF 70 billion in revenue in 2009. Cooperating partners are Agip, Avea, Oi. Győri Szeszgyár distillery in Győr also has bioethanol production capacity (production of potable spirits), but the undertaking is still not present on the Hungarian biofuel market although, according to the plans of the Ministry of rural development, if small holdings producing raw alcohol are set up using aid there is a possibility of investment to expand capacity.

The further development of biofuels consumption in Hungary has been envisaged in the NREAP: 304 ktoe of bioethanol in 2020 (i.e. 475,000 tons).

Irish technology entrepreneur Greg Turley (Pannonia Ethanol Zrt.) has emerged as a major backer of a 120 million euros bioethanol production project in Hungary. It is building an ethanol plant in the town of Dunaföldvár in central Hungary, in conjunction with Fagen, an US firm that has built over 60\% of the bioethanol plants in America. The plant is expected to be operational early in 2012. It will employ
about 80 people when it is completed, taking in 575,000 tons of maize annually to produce 240 million litres of bioethanol, contributing to a more stable and long term market for Hungarian corn which will help increase rural incomes. The plant will also produce 175,000 tons of high protein animal feed that will be available to local farmers. In addition to the 77 direct jobs being created, the project will indirectly support 250 jobs during the construction phase and over 600 once the plant is operational. The facility will use state of the art technology and produce some of the cleanest and most sustainable ethanol in Europe. The project will advance the EU goal for energy independence in the transportation sector.

11.4 France

After the announcements in 2004 for attaining the Directive 2003/30/EC objectives, an amount of ambitious measures were taken to encourage biofuel production and speed up its development. As a result, the objective of incorporating 5.75% biofuel in fuels, initially planned for 2010 in Directive 2003/30/EC, has been brought forward to 2008 and the objective by 2010 increased to 7%. By 2020, France will ensure that suppliers reduce GHGs, produced over the whole fuel life cycle, by at least 6%, in compliance with Directive 2009/30/EC relating to fuel quality. This reduction is calculated compared to the average of European GHGs for 2010. Moreover, the “Grenelle I law” provides for several measures intended firstly to reduce the use of fossil fuels and secondly to promote the development of transport methods using renewable energy sources.

Bioethanol consumption and production

In France the bioethanol consumption for transport sector was in 2008 414,661 toe, in 2009 455,933 toe and in 2010 490,112 toe, showing an increase. The production plants in France at the end of 2009 were 12: 6 plants of TEREOS, 1 plant of Abengoa Bioenergy, 1 plant of CropEnergies and 4 plants of Cristanol. The bioethanol production in France is mainly based on cereals, but some plants use also residues of the wine industries mainly from the distilleries (i.e. marcs).

Incentive measures

General incentive measures have been put in place to promote the replacement of fossil fuels by renewable energies. In addition to the domestic consumption tax on petroleum products, France supports the implementation at European level of a climate contribution system, which subjects all fossil fuels to taxation. To permit the achievement of ambitious targets for the inclusion of biofuels, four types of measure have been implemented:

- the increase of inclusion percentages in fuels distributed, with in particular the launch on 1st April 2009 of SP95-E10 in the petrol sector;
- the authorisation of fuels with a high biofuel content, with in particular E85 in the petrol sector and B30 in the diesel sector;
- the introduction of double counting for biofuels resulting from waste in the 2010 finance law;

In addition, fiscal incentives have been put in place:

- an additional levy of the general tax on polluting activities must be paid by oper-
ator (refiners, supermarkets, independents) who make available for consumption fuels containing a proportion of biofuels lower than the national targets for inclusion set since the Finance Law. The levy amount is highly penalising and incites operators to achieve the annual target:

- a tax exemption through the partial exemption of the domestic consumption tax for biodiesel and bioethanol and a total exemption for pure vegetable oils used as fuel in agricultural and fishing. This tax exemption enables the compensation for the extra manufacturing costs of biofuels compared to fossil fuels. It only applies to biofuels produced by units having been approved after a call for tenders published in the official journal of the EU. This exemption amounted to 720 million euros for 2008 and 521 for 2009. The amounts are adjusted each year in the finance law to take into account the development of economic conditions. The 2009 finance law therefore set the unit amounts (€/hl) of the tax exemption until 2011, with a progressive decrease in the tax exemption.

It should be noted that the double accounting of biofuels produced from used oils and animal fats has been introduced in the finance law for 2010.

Finally, a certain number of measures have been put in place in order to promote the renewal of the automobile stock and thus to replace heavily-consuming vehicles by new, more economical vehicles:

- the scrapping premium of 1,000 € in 2009 is revised downward in 2010 with 700 € in the first half year, then 500 € thereafter. It was removed in 2011;

- the ecological bonus promotes the purchase of a more economical vehicle. In 2010, the bonus ranged from 100 to 1,000 € for vehicles emitting less than 155 gCO₂/km. It reaches 5,000 € for the purchase of a vehicle emitting less than 60 gCO₂/km (hybrid or entirely electric vehicle).

Under France’s finance act (Article 32) of 2005, to encourage the incorporation of biofuels in diesel oil and petrol, all operators (refineries, supermarkets and independent sellers) who sell consumers fuel containing a proportion of biofuel which is less than the national incorporation objectives must pay additional general tax on polluting activities. The rate is decreased by the portion of biofuel marketed in percentage net calorific value, both for petrol and for diesel oil. In order to achieve these ambitious objectives, the French Government has maintained the system of partial exemption from the interior consumer tax which compensates the extra costs of biofuel production in relation to fossil fuels. This tax exemption is allowed for biofuels produced by production plants that have received approval after an invitation to bid published in the official gazette of the EU. The rates are adjusted

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<th>Year</th>
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<td>2011</td>
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Table 61: changes in rates of tax exemption set under the finance act since 2004 (in €/hl). For bio-ETBE only incorporated bioethanol benefits from tax exemption.
every year as part the finance act to take into account any changes in economic conditions. The Government is considering the possibility of delete gradually the system of partial exemption in 2012.

11.5 Portugal

Portugal is developing actions to increase and improve the environmental issues in the energetic laws, with base in the “Estratégia Nacional para a Energia” 2005/169 (Energetic National Strategy). In this context, all the efforts are to look for a more sustainable energy using the best available technology and, in long term, to support the development of new technologies.

According to the RED the target for the share of energy from renewable sources in gross final consumption of energy in the year 2020 for Portugal is 31%. The Directive has a mandatory 10% target for transport to be achieved by all Member States, which refers to renewable sources as a whole, not biofuels alone.

Following the indications of the NREAP, the two most important biofuels are projected to contribute 450,000 toe (biodiesel) and 27,000 toe (bioethanol/bio-ETBE) by 2020. The Directive 2003/30/EC was transposed into Portuguese law in January 2006. The biofuel quantities applied were 2% in 2006, 3% in 2007, 5% in 2010 (percentages of the previous year’s consumption of petrol and diesel). Ministerial order 2009/353-E, enacted on 3rd April 2009 established a system for calculating the minimum and maximum prices that will inform the contracts under which biofuel will be acquired from the national biofuel industry for use on the national market, using international product and currency quotations for the purpose.

The target of 10% of RES in the transport sector will be achieved by means of 85% biofuels and 15% renewable electricity, using multiplication factors for road electricity and biofuels from waste, as envisaged by the RED (89% of biofuels and 11% renewable electricity, in real terms).

For some countries like Portugal, where there exists a clear deficit on the food trade balance, biofuels policy and its effective achievements may be considered a lost opportunity to stick farmers to their lands, thus fighting the abandon of agriculture and subsequent rural migration, and to return to the production of some important food productions (like maize or wheat) that, when the second generation of biofuels arrive, and the biofuels’ business fundamentals change, could well be deviated for food production purposes.

The model to support biofuels (21/22 March 2006), valid until 31st December 2010, was based on the attribution of tax exemptions for large biodiesel producers and small dedicated producers. As for the support schemes for investments, some types of projects to produce biofuels, more specifically projects for innovation and technological trials, are eligible for the system of incentives for innovation for technological trials and the system of incentives for research and technological development. These systems of incentives attribute subsidies that range from 35% to 55% of eligible expenditure.

The model provides for a mechanism to support the use of biofuels produced from waste, residues, non-food cellulosic and lignocellulosic material, as well as the use of endogenous non-food raw materials, as an incentive to introduce new raw materials that do not exert pressure on the food industry.
No bioethanol plants in Portugal in 2011. Global Green, an international platform for the promotion of renewable energy, wants to build Europe’s first bioethanol plant in Portugal. The plant would be located in Idanha-a-Nova, and would use idle tobacco fields to plant sugarcane as raw material for the fuel. The total investment is estimated at 140 million €.

11.6 Croatia

Croatia is a country with good natural potentials and possibilities for the use of RES. The importance of RES in Croatia was recognized already in ‘70s and ‘80s of the last century (i.e. when Croatia was a part of former Yugoslavia) when well-developed R&D programs promoting solar, wind, biomass, and geothermal technologies were established and supported with legislative and financial measures. However, after Croatian independence, RES were not in the focus of the official energy policy and the potential of RES was somewhat neglected. In recent years, due to political reasons (i.e. EU accession process, ratification of Kyoto Agreement) the issue of RES became very important. Croatia has harmonized the overall concept of energy sector reforms with the legal and institutional EU requirements, within the limits of specific national solutions.

The energy act and the energy strategy of Croatia stipulated positive attitude towards RES and the use of RES became one of the strategic goals of the national energy policy. The Croatian energy policy today is directed towards increased efficiency, security of supply and diversification, market deregulation, the use of renewables and environmental protection. The development of Croatian RES market is of great importance for the Croatian economy because it reduces its dependency on the import of electrical power and fossil fuels and decreases overall emission of GHGs. In the long run, market development will improve the climate for private investments in RES in Croatia; increase the use of national equipment and services, resulting consequently in job creation. Therefore, recently there were numerous scientific and popular discussions, symposia and initiatives regarding use of RES. Moreover, in the last ten years in Croatia numerous initiatives and expression of intention and interest for starting energy production from RES by foreign and domestic investors were recorded, but until now many project implementations have failed due to the lack of financial support.

The transport sector represents about 30% of the total final energy consumption, with a very high growth rate (i.e. more than 5% annually over the past five years). Road transport accounts for 90%, the largest share of energy consumption in this sector. Given the rise in number of cars, longer average distances covered by car and fewer individuals travelling in each of the vehicles, this trend is expected to continue in the future.

The consumption of biofuels in Croatia is not sufficiently developed. The biodiesel production started in 2006 and the share of biodiesel in total diesel consumption in 2006 was only 0.4%. Because of the fact that the total biodiesel production decreased in 2007, due to the lack of feedstock, this share dropped to 0.2% in 2007. Biodiesel is sold only at petrol stations owned by biodiesel producers and, so far, it cannot be purchased at other petrol stations in Croatia. Certain major towns in Croatia are investigating the possibility of introducing biodiesel as a replacement...
fuel for diesel in buses used for public transport. The largest progress in implementation of this measure has been made by the City of Zagreb, where biodiesel is used in public transport since beginning of 2007.

The Government supports oilseed production in a way that this production is subsidised with the highest amount of subsidies compared to other annual crops. The subsidy for rapeseed is about three quarters higher than those for wheat and maize, farmers are still reluctant to switch from the traditional cultures to new ones. It is expected that only significantly higher margin could motivate farmers to switch to rapeseed production.

**Bioethanol plants and actual situation**

At the beginning of 2010 there was no production of bioethanol in Croatia. Future production of bioethanol in Croatia will certainly rely on production of wheat and maize as the two most important arable crops of the country. The area under wheat increased in the last 5 years by 13%, while the harvested area of maize decreased by 5% in the same period. Due to the unorganised market for cereals and uncontrolled exports of maize in some years there were severe problems in domestic livestock production. Therefore, in order to meet the needs of raw materials for future bioethanol production, there should be an increase of maize and wheat production, which can be achieved by increasing the harvested area or by increasing the average yield per hectare.

With more than 3.15 million hectares of agricultural land, Croatia has capacity for both large scale agricultural production and production of biomass for biofuels. Croatia offers a long term concession and privatization of state owned land in areas of state concern to include collecting prizes, investment incentives and subventions. Croatia and the rest of the Balkan region has large scale areas of arable land not in use today. The main challenge is the small private owned plots from the socialist period were most land were nationalized.

**11.7 Where the transferability of the EU model does appear possible?**

The previously described scenario allows a comparison of the selected countries for the possible sweet sorghum based model transferability.

**France** has reached the 2010 target 2 years before and is a country well developed in biofuel production, with 12 active bioethanol producing plants. Bioethanol is almost not imported and there are several measures for biofuel development as Government incentives to the production, fiscal incentives, tax exemptions and also promotion for the purchase of ecologic cars by the citizens. In this country there is a good suitability of the climate for sweet sorghum cultivation that can allow good yields in biomass. Nevertheless in France the competitiveness with big industrial groups which are producing bioethanol from cereals is strong. For this reason the involvement of farmers should be required as a priority, also creating cooperatives that can cultivate sweet sorghum for the decentralised plants with incomes for them deriving also from the selling of bioethanol. Unfortunately the electricity in France is mainly produced by nuclear power and the FIT for electricity from biomass is not very high; as a consequence of these aspects, the section of biorefinery for electricity production can be considered of lower importance. The
transition to sweet sorghum cultivation and decentralized plants should be stimulated involving the farmers in a profit higher that the selling of biomass.

**Romania** has more than 10 investments in bioethanol plants in progress, but there is not a good development of the filling stations and also the promotion of the use of biofuel is not well known by the public. In the last years a number of actions have been initiated in order to contribute to the promotion of use of biofuels and other renewables. Bioethanol is mainly produced by maize and for this crop like for other energy crops financial assistance is foreseen for the farmers by the Government. For this reason should be possible to introduce sweet sorghum for bioethanol production, also because Romania has a lot of hectares of land to cultivate for stimulating the agriculture. A program for the National Rural Development has been started by the Government with particular attention for the RES and it foresees a change in the crops cultivation in favour of new crops to introduce. For this reason sweet sorghum should be cultivated for bioethanol and power production from its by-products. While in France the competitiveness with big industrial cereal groups is strong, in Romania, with a lot of land and no big bioethanol production plants, the possibility of having decentralised small-medium plants with a certain amount of involved farmers could easily become a reality.

In **Hungary** there is a constant increase in the use of bioethanol in transport sector and also the Government with different decrees imposes fines if the blending ratio is not reached giving incentives for reaching the targets. There are also incentives for the construction of bioethanol plants even if the considered crop for this purpose is maize. The NREAP foresees a growing bioethanol consumption by 2020 and will favour the starting of new plants with maize. For these reasons, the sweet sorghum based model can be applied both for the land availability and for the Government support. The involving of farmers in cultivating sweet sorghum instead of maize could be possible also thanks to the probable good biomass yields in this country, like in other eastern EU countries. The model based on involving of farmers also in the sharing of the profits could be a very strong incentive.

In **Bulgaria**, there is bioethanol production from some plants, but the main part of bioethanol is exported (in 2009 about 20,000 tons of bioethanol produced but for the internal market just 350 tons were used). In 2011, a stop of the Government in the blending of 5% biofuels occurred, because the petrol or diesel oil with part of biofuel are more expensive for the final user and for the producers. For this reason there is now uncertainty for the farmers in cultivating energy crops for biofuel production because there is low request. For transferring the sweet sorghum based model in Bulgaria the most important thing to focus is the power production from the by-products and the possible profit for the farmers also from this production is the electricity. In the last years the incentives for electricity production from RES were almost absent in Bulgaria. Recently the legislation is changed: there are incentives up to 15 years (84-110 €/MWh ) and there is a low fiscal pressure in the country.

The situation of Portugal and Croatia is different and maybe the transferability of the model can be lower.

**Portugal** produces a lot of renewable electricity from wind power and hydro-power. The biofuels production is not diffused and they are mainly imported. There is an
abandon of the agriculture and rural areas and the Government is going to incentive the crop production just for maize and wheat. For this reason bioethanol might be produced by cereals and with difficulty by sweet sorghum. There are incentives for innovative projects but not for the plants and up to the half of 2011 there were no bioethanol plants at all.

**Croatia** in the last few years started its interest in RES and also the transport sector is the 30% of the final energy consumption of the country with a high growth rate. There is a very low biofuel consumption and there is lack of feedstocks even if the incentives for energy crops are higher than the incentives for food crops. The farmers are very reluctant to change the cultivations. There were no bioethanol plants in 2010. The transferability is difficult even if sweet sorghum could be cultivated well in this country. The model of decentralised plant with a group of farmers that cultivate this crop appears still far from the Croatian agriculture.
12. EXPERIENCES OF THE VISITS OUTSIDE AND IN THE EU

In order to refine the know-how about the sweet sorghum processing in bioethanol, some visits were planned. The destinations were chosen to visit some agricultural institutes where germplasms are studied and bred, and some plants where sweet sorghum is processed in bioethanol at the pilot and industrial scales.

Since this chain is not developed in the EU because of important non-technological barriers, some destinations were outside the EU.

The travels were carried out in October and November 2010.

The obtained knowledge, concisely reported in the following paragraphs, was the background for the discussion of the EU model, carried out in the consortium countries with the participation of the stakeholders and aimed to import the know-how and to start new entrepreneurships in this sector.

12.1 India

India was selected for the visits because it is one of the few existing countries around the world where sweet sorghum is being used for the bioethanol production.

In November 2007 the M/s Rusni Distilleries Pvt Ltd at Hyderabad (Andhra Pradesh) started to produce bioethanol by processing sweet sorghum.

One year later, on December 2008, TATA Chemical Ltd created a bioethanol plant in Nanded (Maharashtra), using sweet sorghum as feedstock too.

Food security is a national priority for India due to the fact that about one-fourth of the population is below the poverty line, so India’s biofuels strategy focuses on the use of non-food sources. Sweet sorghum allies to this policy because it does not compromise food security for the bioethanol production since the farmers can continue to use the grain for food.

The Indian Ministry of petroleum launched a program that imposed blending of 5% bioethanol in petrol in 2003. The implementation of the program in many States was delayed because the high State taxes, excise duties and levies made the bioethanol supply for blending commercially unviable. It is estimated that about 540 million litres of bioethanol have been supplied for the program by the end of April 2009.

The Government does not provide any direct financial assistance or tax incentive for the production or marketing of bioethanol or bioethanol-blended petrol; however, offers subsidised loans (2% below market rate) from the national–held Sugarcane Development Fund for up to a maximum of 40% of the project cost to sugar mills for setting up an bioethanol production unit. More than 115 out of the 320 alcohol distilleries modified their distillation facilities to produce bioethanol with total production capacity of 1.5 billion litres per year.

In India the production of bioethanol is derived mainly from sugar by-products, while the use of other feedstock, like sweet sorghum or sugar beet, is at a preliminary stage.

The Government supports researches for identifying sweet sorghum cultivations suitable for the local climate and supports also some public research organizations, such as ICRISAT.

ICRISAT is headquartered in Hyderabad (Andhra Pradesh), and its mission is to “help empower 600 million poor people to overcome hunger, poverty and a degraded
environment in the dry tropics through better agriculture”. The institute focuses on five crops: groundnut, pigeon pea, sorghum, chickpea and millet.

ICRISAT carries out an extended research on genetic, enhancement of sweet sorghum for sugar yield. Research on the development of sweet sorghum cultivars was initiated in 1980 with the evaluation of 70 germplasm accessions and was renewed in 2002 to meet the increased demand for bioethanol, driven by Government policies to blend bioethanol with petrol. The wide variability in germplasm and hybrid parents for the traits related to bioethanol production, such as sugar content and high stalk yield, offers bright scope for the development of high stalk yielding sugar-rich varieties and hybrids. The sweet sorghum breeding program aims to improve the sugars content, the juice content and the plant biomass apart from sugar yield. Hybrids are superior for sugar yield and are less thermo and photoperiod insensitive.

ICRISAT established in 2003 the ASP to promote public-private partnerships that will commercialise science-generated technologies. So far more than 20 technologies have been marketed through the private sector, thus creating employment opportunities and industrialisation.

A key success story has been the commercialisation of bioethanol from sweet sorghum when ICRISAT developed hybrids that yielded high juice and sugar content for industrial production of bioethanol, and the technology was successfully commercialized by M/s Rusni Distilleries Pvt Ltd.

ICRISAT has created also two platforms:

1. the ICRISAT – Private Sector Sweet Sorghum Ethanol Research Consortium has been established to meet current and future demands of the sweet sorghum-based bioethanol distillery units, and this is being facilitated by ABI of ICRISAT;

2. the ICRISAT – Private Seed Sector Sorghum Hybrid Parents Research Consortium operates with 22 members at present and aims to strengthen sweet sorghum hybrid plants research at ICRISAT and shares the products of this research with the seed industry, which in turn provides sweet sorghum hybrids to the farmers.

Sweet sorghum supply chain involves centralised and decentralised models. Under centralised model, farmers supply the sweet sorghum stalks directly to the distillery, whereas in decentralised model farmers supply stalks to DCU which act as cluster centres. To enable farmers who are located away from the distilleries to participate in the sweet sorghum to bioethanol value chain, a decentralised crushing and syrup making unit is proposed involving farmers from a cluster of three to four villages.

ICRISAT’s strategy is to examine the feasibility of applying one or more of these measures to mitigate the yield losses and help supply raw materials (stalks or syrup) to the distillery over an extended period in a year. In the DCU units, stalks are crushed and the sweet juice is boiled to produce concentrated syrup (> 60 °Brix) that can be stored for more than 9 months and can be used in bioethanol production, particularly in off-season, increasing the feedstock supply to the distillery. The DCU of ICRISAT processes the sweet sorghum crops of 70 farmers, with the supply from about 30 hectares. The unit has 3 crusher machines two of which have a capacity of crushing 2 tons of stalks/hour while the other has a capacity of 1 t/h. In the 2009 rainy season, a total of 560 tons of green stalks were crushed to realize 29 tons of syrup (approximately 60 °Brix).
M/s Rusni Distilleries Pvt Ltd is the world’s first sweet sorghum based bioethanol plant. It’s a mid-sized plant with a capacity of 40,000 litres of bioethanol per day (in full operation). The plant has 30 crushing units of 1 t/h capacity each, and 6 tanks for the fermentation phase and the syrup production. M/s Rusni Distilleries Pvt Ltd apart from the sweet sorghum syrup supplied by the cluster centre (i.e. DCU) buys sweet sorghum stalk for 9-10 € per ton from other farmers near the area. The bioethanol plant process 870 tons of sweet sorghum stalks. All the stalks passed in a series of 2 rollers and they are so crushed twice; the juice yield corresponds to an extent of 40% of stalk yield on weight basis. Juice is pasteurized at 100 °C for 30 minutes; yeast is added and fermented for 34 to 45 hours. The production cost of bioethanol is approx 0.30 €/litre, while the public outlet pays 0.40 €/litre and the private outlet pays 0.46€/litre of bioethanol.

The cost of the plant was about 7 million €.

The plant of the TATA Chemical Ltd has a capacity of 30,000 litres of bioethanol per day and uses also sweet sorghum bagasse as fuel for generating power. Sweet sorghum stalks are transported to TATA Chemicals Ltd plant unloaded on the feeder carrier to be discharged to the fibrizer. The raw material pass through 4 power operated hammer mills of 3-roller mill
(TRPF milling system) to collect the juice. The extracted juice is then carried to the furnace for syrup production and evaporation. If the syrup must be carried directly for fermentation, sugar is concentrated about 40-50% (semi-syrup) and then diluted to 18%. The syrup of 85°Brix, conserved for about one year, is also diluted before the fermentation. The juice is then inoculated with yeast and run in fermentor for a period of 72 hours at 30-32 °C. Finally, after the fermentation, the distillation phase takes place for the production of bioethanol.

**Topic: Synthesis of the model developed by ICRISAT**

A DCU is a place where the sugar juice is extracted from the sweet sorghum stalks. Each DCU can manage 70 ha of sweet sorghum. Sweet sorghum average yield is 30-35 t wb/ha. Juice extraction yield from stalks is 65-70% and losses percentage is estimated about 5-10%. Sugar content can reach 17 ºBrix. Bagasse (30%) is burned in furnaces as a source of heat to concentrate the juice extracted from stalks and converted it into syrup (80% concentration) in order to improve the storage conditions and facilitate the transport to distilleries plants. One ton of juice produces 170 kg of syrup. The rest of bagasse is sold or used for domestic uses. Climate conditions allow to have two crop seasons, rainy and post-rainy season (4 months each one) and a rotation period of 4 months too. Fertilisers (NPK) are usually applied in three times and they are complemented with nitrogen fertiliser, 30 days after sowing. Spatial plant arrangement is 0.75-0.80 m x 0.10-0.15 m, and it is superficially sown (=5cm) using ridge rows. Irrigation is applied but the water amount depends on the climate conditions. Land is ploughed before sowing and herbicides are used according to the requirements. Due to the low labour costs the degree of mechanization is very low; because of economic limitations, crop inputs (fertilizers, herbicides, pests) are low too.

**Figure 39: scheme of the ICRISAT’s model**

<table>
<thead>
<tr>
<th>Sweet sorghum fields</th>
<th>560 tons fresh biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 harvests/year, rotation with cereals and legumes</td>
<td></td>
</tr>
<tr>
<td>Extraction of the sugar juice at the DCU</td>
<td>29 tons sugar juice 60 Brix</td>
</tr>
<tr>
<td>Processing in bioethanol at the Rusni Distilleries Pvi Ltd</td>
<td>10,000 t/y bioethanol, processing feedstock from 950 farms within 60 km</td>
</tr>
</tbody>
</table>
12.2 Peru

Peru is a country in which the incipient development of bioethanol production and use is having a particular impact on industrial, agronomic and social development. Its history in the biofuel sector began a few years ago, following the footsteps of other nearby countries such as Brazil, Colombia or the US. In this case, the development of bioethanol production in Peru has had an economic and environmental justification. This last justification is due to the high level of pollution that can be found in cities like Lima, mainly due to the traffic.

Considering all these factors referred to Peru, this country was chosen to evaluate the reality of a new situation referred to the bioethanol production, promotion and application.

Peru has a large tradition on the sugar production from sugarcane. Now, this raw material is used for producing bioethanol, applying high level technologies to increase the productivity and quality of the sugarcane in semi-desert areas or areas with a low productivity.

The production of bioethanol from sugarcane is the most extended system to produce this biofuel. This affirmation is based on the production of bioethanol in Brazil, which is the country with the largest production of bioethanol followed by the US. Both countries have applied important politics to promote the production and application of the bioethanol as biofuel. At this moment, sugarcane is one of the most important raw materials used all around the world to produce bioethanol, mainly due to the high yield of its productivity and to the high production per hectare of bioethanol. Apart from this, the energy balance using sugarcane as raw material is very good, considering that 100% of the energy consumption during the bioethanol production is covered by the same crop (with the bagasse, which is the biomass generated after the extraction as already mentioned above).

The use of sugarcane for bioethanol production in Peru has been made considering the social and the environmental aspects. This aim has taken into account the development of desert and semi-desert areas as a priority. This development fits well with the sustainability required for the production of bioethanol by the RED, as it allows the transformation of desert areas without any kind of productivity into productivity areas with similar yields of high quality areas.

Good examples of this transformation are the industrial and agricultural projects developed by Maple Energy Inc. and Ethanol plant Caña Brava in Sullana (Piura region).

Bioethanol production is not still widespread in the country, focusing mainly in the region of Piura by Caña Brava, with its production plant (capacity 350,000 litres per day), and the future plant of Maple Energy Inc., both from sugarcane.
The rest of the sugar mills in the country are not still producing bioethanol fuel. The development of a new legislation will ensure the blending 7.8% of biofuel (bioethanol) with fuel. This new legislation will promote the development of rural areas and, of course, allow the development of a new type of industry.

12.3 Spain

In Spain during the month of October 2010 there were different visits, one to the bioethanol plant of Abengoa in Babilafuente, Salamanca, and another to the ACOR Cooperative in Olmedo, to visit its sugar production plant from beet and biodiesel from sunflower and rapeseed. Spain, given its cereal tradition, has based its bioethanol production on cereals like wheat. The process is based on the dry milling and enzymatic hydrolysis of starch. In Spain, despite being a producer of cereals which could be used for bioethanol production, most of the raw materials used for this production are imported from other producing countries, where the cost per kilogram of raw material is lower and therefore allows obtaining a final tighter cost per litre of bioethanol. Thus, the percentage of cereals used for industrial destinations for bioethanol production in Spain, is less than 7%.

Abengoa – Bioenergy Group has three bioethanol plants in Spain:
- Biocarburantes Castilla y León (located in Babilafuente, Salamanca).
- Bioetanol Galicia (located in A Coruña, Galicia).
- Ecocarburantes Españoles (located in Cartagena, Murcia).

In the case of the plant located in Babilafuente, cereals, especially wheat and barley, are the selected raw materials for the bioethanol production. In any case, it should be noted that the distribution in Spain has followed a defined pattern for the three industrial operating plants. For the first two cases, both located in Cartagena and in A Coruña, the main product was anhydrous bioethanol for ETBE production, so its location has been decided considering the proximity to a port for the introduction of raw materials and close to a refinery for further processing of bioethanol into bio-ETBE. This change in the type of final product, and in the trend of use, originated the selection of the third production plant in Spain, located in Babilafuente, in the middle of a cereal-producing area, such as Castilla and León region and...
close to a temporary storage area of petrol, which would facilitate the blending or direct mixing, during loading of tankers, for subsequent distribution to the national stations. The only difference between the three production plants that Abengoa – Bioenergy Group has in Spain is that in the case of the Cartagena plant, the fermentation is carried out in continuous process, whereas in the cases of Salamanca (Babilafuente) and A Coruña, the fermentation stage is carried out in batch. Abengoa – Bioenergy Group is a company for bioethanol production and not an agricultural company and, therefore, it does not control neither production nor the price of raw materials. Consequently, the company cannot consider the development of small and medium scale plants as an alternative, like the main objective of the SWEETHANOL Project. This aim could be achieved if the model varies, involving producers of raw materials in the same production process. This alternative sought model, in which SWEETHANOL Project intends to base, is that ACOR Cooperative shows in its sugar production plant from beet and biodiesel from sunflower and rape-seed.
13. PILOT EXPERIENCES IN THE EU

13.1 IMA - Bertolino Group in Italy

In Italy the most important bioethanol production plant is located in Sicily in the city of Trapani and recently the processing of sweet sorghum as bioethanol crop has been tested at pilot scale.

The owner is IMA (Industria Meridionale Alcolici) of the Bertolino Group. IMA was established in 1982 and started its activity of moving and storing alcohol in its coastal deposit of Trapani close to the port facilities, to which is still bound through two pipelines for the operations of load-unload of the ships and cargo boats. In 1990 the society decided to invest in the construction of a bigger plant, first in Italy, with molecular sieves for the production of dehydrated bioethanol at 99.9% v/v (i.e. bioethanol as transport fuel) and the capacity of the plant was 300 m³/day. Since that time, IMA increased its capacity of storage and today it counts of a deposit tanks park able to storage up to 36,000 m³ of bioethanol, together with an increment of the production capacity because of the doubling of the plants for a total of 600 m³/day production. The capacity of storage is made of 26 tanks connected with the two pipelines and to the production plants. The produced bioethanol is stored in tanks dedicated to it that are different to those for the introduction of the raw product to dehydrate. The pumping rate, load/unload boats is of 300 m³/h and the accessibility to the port is allowed for all boats up to draught of 8 meters.

The position is in the centre of the Mediterranean sea as a passage route for the cargo boats coming from Black Sea and directed to the Straits of Gibraltar and vice versa, together with its collocation that is strategic in Italy, allow to the IMA plants to answer in a rapid way to the requirements of its clients assuring good services. IMA is recognised as coastal deposit accredited by the Italian Ministry of Transports and Navigation, it is cited in the navigation maps and it is also the first pilot plant in Italy that has been recognised by the EU in the art.92 of the EC regulation 2000/1623.

The plant of IMA is the only one that produces bioethanol for the blending and for the bio-ETBE synthesis, while the other ethanol plants are producing ethanol for industrial uses and not for transport (i.e. Caviro Group, Silcompa S.p.A.).

The experience matured by IMA attracted the attention of the cars construction companies and recently also the BMW Sustainability Press Experience recently has visited the plant.

Commonly bioethanol is imported as raw alcohol to dehydrate and transform in bioethanol of high purity. Concerning the raw ethanol importation, IMA gets this material from Turkey, Romania and Spain. In the last years Brazil and Pakistan have been the main suppliers but today the convenience in these countries is reduced. Actually, the IMA plant gives its pure bioethanol just to the bio-ETBE conversion plants even if its quality is compatible also for the petrol blendings. The problem in Italy is correlated with the fact that the refineries tanks have a head of water caused by the transport of oil products by boat. To avoid the absorption of water by the product during the storage in the tanks, the blending the pure ethanol with petrol directly on line is the possibility in phase of evaluation: the blended product...
should go directly to the filling station for the consumption and each filling station should choose between E5 or E10. In other countries this situation does not occur because they do not use water for the washing of the storage tanks.

As regards the pilot experience of IMA about the sweet sorghum utilisation, a project has been started for bioethanol production using this crop, that is well adapted to the climate of Sicily and evidences good biomass yields. The model promoted by IMA with sweet sorghum is based on the first and second generation technologies, it is carried out in cooperation with Mossi & Ghisolfi Group (Chemtex Italia S.p.A.) and the details of the processing (e.g. technical sections, energy balance) are covered by trade secret.

Concerning the biomass supply, the foreseen maximum range is 50 km from the processing plant and the yields have been good in the last three years of experimentation, if irrigation is applied.

The main point of the already started initiative is to guarantee the maximum profitability for the farmers and the agri-entrepreneurs in order to motivate them in the participation. The model foresees also that the farmers dedicate for the sweet sorghum production the non-food land (i.e. marginal lands or set aside) not subtracting land to the traditional food crops (i.e. citrus orchards and vineyards, typical in Sicily). The plant processes the biomass optimising the valorisation of the by-products (i.e. biogas production and cogeneration) in order to economise the industrial process. The incomes must be divided between the industry (i.e. the owner of the plant) and the farmers that in this way can count on two profits: the biomass selling and the part deriving from the industrial plant. In the model is foreseen of alternating the sweet sorghum processing with other biomasses (i.e. second generation production) for guaranteeing the functioning of the plant in continuous. In fact, bioethanol plant should be at full regime in order to work 330 day/year (i.e. the necessary time of working for having a good sustainability) and for this reason the diversification of the raw materials to process is very important also in the perspective of protecting the production in case of bad agrarian years. A particular attention must also be posed on the management costs that for plants of this typology (i.e. referable to a distillery) are very high and so, the production is sustainable just if the functioning is guaranteed for 330 d/y.

The experience of the IMA bioethanol plant that is working with sweet sorghum is a very important reality for transferring the model proposed by the project in Italy. This could be the first example to propose for replicating it in other EU countries allowing the production of bioethanol in loco reducing the importation and with the involvement of the farmers in the creation of this short chain.
14. CONCLUSIONS

Considering all information reported in this manual, both for technical and administrative aspects of the sweet sorghum based model for bioethanol production, some important conclusions have been elaborated.

As regards the viability of the EU model in Italy, basing on the current situation the following remarks emerge:

- the 1st generation bioethanol produced from sweet sorghum is insufficiently supported by the current incentives (i.e. +10%) and it is not competitive compared to the 2nd generation one (+100%);
- the reward of electricity produced from bagasse of sweet sorghum and from vinasse is promising, because it can benefit from the all-inclusive tariff, which ensures fixed market conditions and reduces the business risk. The values of the all-inclusive tariff for each RES is being determined and they could confirm this remark;
- the reward of heat is promising through the White Certificates, about which the forthcoming decree will determine the values and duration. Consequently the EU model is consistent with the Italian strategies for using RES in the electricity and heating sector, whereas this statement is not really correct for the 1st generation bioethanol.

It is important to underline that the current situation is not completely clear, because some important variables persist at the present time: especially the values for the all-inclusive tariff and White Certificates can influence significantly the economic viability of the model. The current situation should be definitively cleared at the beginning of 2012.

In the framework of the SWEETHANOL project some representatives of MSE and MIPAAF have known the contents of the EU model and they have understood and shared the approach towards the decentralised bioenergy production. In the round tables aimed to draft the attached implementing decrees of the legislative decree 2011/28 the EU model may be taken into consideration and eventually awarded.

As regards with the existing experience and their evolution benefiting from the project results, IMA is considered an interested stakeholder.

In Greece at the moment there is no bioethanol production, and the EU targets on biofuels are faced just with biodiesel production.

With the national law 2005/3423 the Directive 2003/30/EC has been enforced enabling the production, import and trading of biofuels. Focusing just on biodiesel Greece still lags in the production of bioethanol to introduce in the petrol blendings.

With the current evaluations, there are some important success factors that may affect the profitability of a bioethanol chain, if developed.

One of them is the Government legal framework together with the supporting policies, in fact to ensure the financial viability of the bioethanol plants, incentives by the Government should be provided and all the legal issues for motivating the new investors to proceed with the plants dealing with less bureaucracy issues should be
addressed.

Another factor is the sustainability of the feedstock supply for creating the short chain to produce bioethanol in specific areas, introducing the sweet sorghum crop. For the sustainability of the feedstock the farmers should be assured via contract agreements to sell their entire crop at a fixed price to ensure their profit, also guaranteeing them the incomes deriving from the selling of bioethanol and produced power. Research has shown that sweet sorghum has low needs in water and fertilizers and farmers have a higher economic initiative in cultivating this energy crop since the sugar content per hectare of sweet sorghum cultivation is higher in comparison to other crops.

Finally, the availability of the latest technologies can affect the profitability thanks to higher reachable yields.

The main conclusion is summarized in the great advantage in investing in biomass and biofuels in Greece because of the importance of the agricultural sector in this country, the high FIT for biomass guaranteed for 20 years, the binding of national commitments in biofuel use and the long term legislative framework which is favorable, and can ensure the reliability of the investment.

In Spain, the model for blending bioethanol and ETBE production has been defined and structured for several years, which has allowed the development of several projects and bioethanol production plants, such as Cartagena, A Coruña and Salamanca, belonging to the company Abengoa.

One of the most important regulatory aspects has been the application of a 0% rate to the biofuels mixed with petrol or used for the production of bio-ETBE, which eliminates taxes on the proportional part of such products.

Likewise, the assessment of GHGs on the crops used in Spain for the production of bioethanol on the basis of Directives 2009/30/EC and 2009/28/EC have verified the sustainability of most of these crops, ensuring the continued support and a 0% rate to these biofuels.

It is also important to remember that in addition to the elimination of taxes on those biofuels, in Spain there is a very thorough and precise legislation relating to the payment of electricity produced from renewable sources. In this sector, changes in the premiums paid per kWe produced from biomass, has been a boost to cogeneration facilities from energy crops and biomass from energy crops, as in the case of sweet sorghum. The increase in the premium has obvious benefits associated with the installation of cogeneration plants attached to the industry producing bioethanol from sweet sorghum. This means that over 50% of revenues from these facilities could come from the sale of electricity, which would ensure the profitability of ethanol production.

At this moment, the actual economic situation has impacted over the renewable energies in Spain, and between them, the premiums to the produced bioenergy (electric power generation) have been eliminated temporarily for the new installations. Thus, the evaluation of the investment must include the actual situation, considering that there are no premiums to the kWe produced from biomass during the next one or two years.

The production of 1st generation bioethanol from sweet sorghum in small or medi-
um scale plants would not be profitable as a unit, but the addition to the securities account of the production and sale of subsidized electricity, implies that the investment can be amortized over a set time (between 4 and 6 years).

Although the law of 0% rate for bioethanol has been in effect until 2012, it seems more than likely to extend the application of this law, securing and protecting the production of bioethanol for use as biofuel.

This statement is supported in Spain by the GHGs balance of the crops used, and emerging policy of protection of domestic production of biofuels against outsider producers.

All these details seem to ensure the development and maintenance of the industry of bioethanol production in Spain, already in place since 10 years with the launch of bioethanol production plant of Abengoa in Cartagena (Ecocarburantes Spanish SA) with a capacity of 100,000 m³ of bioethanol per year.

Significant growth is expected in the demand of ethanol due to the increase in the allowable percentage of biofuel in the blend of gasoline, from 5 to 10%, although it should be noted that, in the current context of crisis, the increase of the oil price caused by the instability in some producing countries, may cause a contraction in consumption and a reduction of the expected growth in demand for bioethanol.

Sweet sorghum is a great alternative to other raw materials used in Spain for bioethanol, such as cereals, because of its better ratio in the GHGs balance and a better energy efficiency and economic balance due to the production of residual biomass usable for the production of steam and electricity, unlike other crops such as barley or wheat.
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111 Such schemes pay renewable energy producers a set rate (tariff) for each unit of electricity fed into the grid, and generally oblige power companies to purchase all electricity from eligible producers in their service area over a long period of time.


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This intersectorial manual is one of the main final tools of the SWEETHANOL project and it includes the technical, political, economic and administrative elements of the EU model for using sweet sorghum as bioethanol and bioenergy crop. The EU model is reported as guidelines, which are basic to set up the technical-economic feasibility studies. Furthermore, these guidelines are applied in four case studies in the consortium countries (i.e. Italy, Greece, Spain) which are integrated with the economic analysis and the estimation of the GHGs emission saving, in accordance with the Directive 2008/29/EC.

In order to maximize the transferability of the EU model in other countries, where sweet sorghum can be cultivated, the treatment is completed with the description of the political-economic conditions that are strategic to start up these entrepreneurships in southern European countries (i.e. Bulgaria, Romania, Hungary, France, Portugal, Croatia).

The handbook is targeted to all stakeholders (i.e. farmers, agricultural associations, fuel processors, SMEs, seeds and agricultural companies, investors, policy makers and representatives of public authorities and energy agencies).