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Research Article

Residue Derived Fuels as an Alternative Fuel for the Hellenic Power Generation Sector and their Potential for Emissions Reduction

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Abstract: The European Union Landfill Directive (1999/31 EC) promotes more environmental friendly waste management options, by reducing the amount of wastes and more specific of biodegradable wastes, disposed of in landfills. The EU member states are adopting the mechanical-biological treatment process for municipal solid waste and non-hazardous industrial wastes to comply with the abovementioned Directive's targets on landfill diversion, and produce waste derived fuels such as refuse derived fuel and solid recovered fuel. Waste derived fuels present high calorific values depending on their synthesis and are being used both in dedicated waste-to-energy plants and as fuel substitutes in industrial processes. In this paper the refuse derived fuel and solid recovered fuel production and utilisation options in European Union are presented, and the possibilities in Greece based on the waste production and National Plan for Waste Management of the Ministry of Environment is attempted. The existing and ongoing studies on co-combustion and co-gasification with brown coal support the use of refuse derived fuel and solid recovered fuel as fuel on Hellenic Power Sector, adopting in the existing lignite power plants adequate Air Pollution Control systems. If the co-combustion or co-gasification of these alternative fuels is adopted from the Hellenic Power Sector a reduction on emissions is expected that cannot be neglected.

Keywords: power generation; alternative fuels; Refuse Derived Fuel; Solid Recovered Fuel; waste-to-energy; co-combustion; emissions reduction

1. Introduction

Economic development is always accompanied by higher consumption of goods and services and attendant increased generation of solid wastes that need to be disposed somehow. The waste generation today is higher than the economic growth and the different waste management methods applied aim to reduce the significant environmental and economical impact of this fact. In the generally accepted waste hierarchy, the first priority is for waste reduction, followed by recycling and also composting of clean biodegradable organic wastes (food and yard wastes) [1]. European Union's (EU) policy in waste management promotes recycling over other waste treatment methods to recover materials and energy. The energy recovery can be obtained in the form of waste-to-energy or production of waste derived fuels from the remaining waste fraction. In this way physical resources are protected since paper, metals, glass, plastics that can be recovered from waste return in the production lines demanding less resources and energy for their process, while the energy recovery provides with electricity and heat the industrial, commercial and domestic consumers, and at the same time the volume of wastes to be treated is minimised [2]. The goal of combining these approaches supported with the additional option of composting is to minimise the loss of resources to final inert landfill disposal, where the remaining of these processes will be finally placed [3].

Landfilling is the most common method for waste management in many EU Member States, where in some cases the dependency exceeds 80%. The EU Landfill Directive of 1999, which obliges Member States to progressively reduce the amount of organic waste going to landfill to 35% of 1995 levels within 15 years, aims to reduce such a loss of resources. This clear policy direction has put emphasis on waste management systems which actively increase and optimise the recovery of resources from waste – whether as materials or as energy. In order to protect the environment from the emissions in energy recovery facilities EU adopted the regulation on emission limits from waste incineration plants (Directive 2000/76/EC), while the regulation on renewable energy sources (RES) (Directive 2001/77/EC), supports the renewable character that the biodegradable and general organic fraction of wastes presents [3-9].

The EU Member States, in order to comply with the Landfill Directive, adopt waste management methods that involve separation at the source, and use Mechanical-Biological Treatment (MBT) processes. MBT is an established technology to treat municipal and non-hazardous commercial and industrial solid wastes (MSW) and it is already in use for several in different Member States. MBT is a generic term for a number of similar processes treating mixed MSW, or fractions of MSW, in order to recover metals and energy. Through the processes involved during MBT, several output streams are generated, including a compost-like digested material, a high calorific value fuel stream (15–18 MJ/kg), metals, and residuals. If the procedure includes anaerobic digesters biogas can be generated also. The high calorific value fuel stream typically comprises mainly paper, plastic, wood and textiles. This waste-derived fuel from MSW is usually called refuse-derived fuel (RDF) or solid recovered fuel (SRF), depending upon the fuel's characteristics [8-15]. SRF is more homogeneous and less contaminated than the generic RDF and includes in the MBT procedure biological drying, while usually presents higher calorific value. The possibilities for utilisation of this fuel is in existing waste-to-energy plants, cement kilns, dedicated plants, or utilisation as a fuel substitute in existing coal or lignite power plants. Figure 1 presents these utilisation alternatives [1,9,13,16-22].

In this paper the RDF and SRF production and utilisation options in EU are presented, and the possibilities in Greece, based on the waste production and National Plan for Waste Management of the Ministry of Environment, is attempted, focusing the RDF and SRF utilisation in electricity production. The existing and ongoing studies on co-combustion and co-gasification with brown coal and the higher electricity output of RDF and SRF Waste-to-Energy plants support the use of RDF and SRF as fuel on Greek Power Sector. The potential problem of toxic emissions in co-combustion can be eliminated through the use of adequate Air Pollution Control (APC) Systems in the existing Power Plants that combust lignite or brown coal. The adoption of these types of fuels from the

Hellenic Power Sector will result to a reduction on emissions that cannot be neglected.

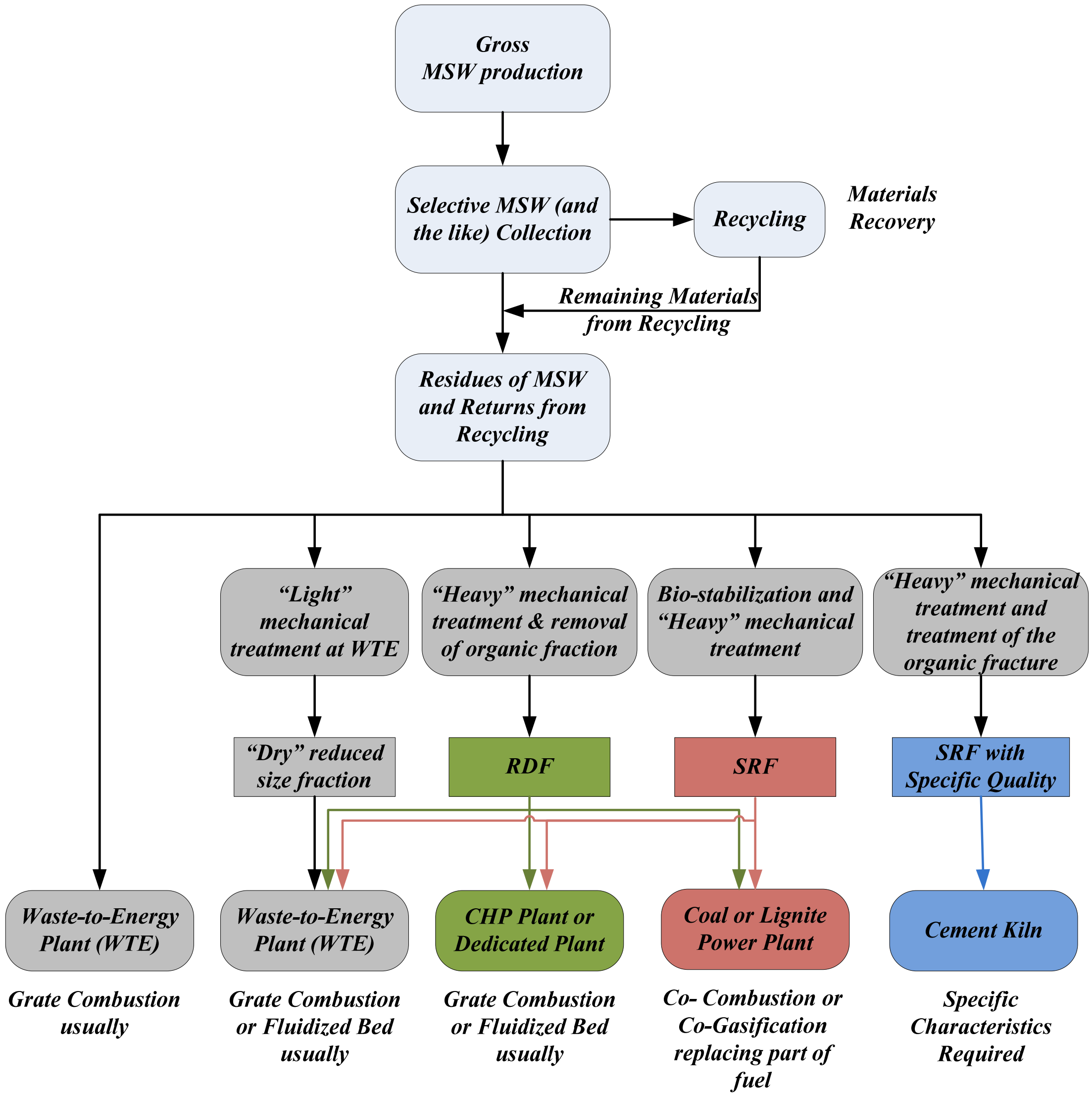

Figure 1. Schematic diagram for RDF/SRF derived from MSW utilisation alternatives.

2. RDF and SRF production and utilisation

2.1. RDF and SRF Definitions

Refuse derived fuels cover a wide range of waste materials which have been processed to fulfil guideline, regulatory or industry specifications mainly to achieve a high calorific value. Waste derived fuels include residues from municipal solid waste (MSW) recycling, industrial/trade waste, sewage sludge, industrial hazardous waste, biomass waste, etc [9,10,12,13,15,23,24].

Refuse is a general term for municipal solid and commercial wastes and the terms 'Refuse Derived Fuel (RDF)' and 'Solid Refuse Fuel (SRF)' usually refer to the segregated high calorific fraction of MSW, commercial or industrial process wastes. RDF and SRF are produced during Mechanical Biological Treatment (MBT) of wastes [9,11,13-15]. Other terms are also used for MSW derived fuels such as Recovered Fuel (REF), Packaging Derived Fuels (PDF), Paper and Plastic

Fraction (PPF) and Process Engineered Fuel (PEF). REF, PDF, PPF and PEF usually refer to a source-separated, processed, dry combustible MSW fraction (e.g. plastics and/or paper) which are too contaminated to be recycled. It has a higher calorific value, lower moisture content and lower ash content (on combustion) than RDF derived from mixed waste fractions. Table 1 presents typical properties of RDF [10,12,13,15,23-25].

Table 1. Typical Ranges of RDF Properties (source [10-13]).

Chemical Properties		Mechanical Properties	
Calorific Value	11–18 MJ/kg	Particle size	10–300 mm
moisture	10–30 % wt	Bulk density	120–300 kg/m^3
ash	10–20 % wt		
Cl	1.0–1.8 % wt		
S	0.3–0.8 % wt		

The terms 'Secondary Fuel, Substitute Fuel and Substitute Liquid Fuel (SLF)' are used for processed industrial wastes which may be homogeneous or mixed to specification. Examples of these fuels include waste tyres, waste oils, spent solvents, bone meal, animal fats, sewage sludge and industrial sludge (e.g. paint sludge and paper sludge). These terms can also refer to non-hazardous packaging or other residues from industrial/trade sources (e.g. plastic, paper and textiles), biomass (e.g. waste wood and sawdust), demolition waste or shredded combustible residues from scrap cars [10,12,13,15,23-25].

Solid Recovered Fuel (SRF) is a "solid fuel prepared (processed, homogenised and up-graded to a quality that can be traded amongst producers and users) from non-hazardous waste to be utilised for energy recovery in incineration or co-incineration plants, and meeting the classification and specification requirements laid down in EN15359 (definition in EN15359). Even though it has been mentioned before that terms RDF and SRF are often used to describe the same waste derived fuel, SRF has to be distinguished from other waste derived fuels (often called RDF), which do not meet the requirements of EN15359 [10,13,15]. There are 125 SRF classes, based on limit values for the mean value for net calorific value (NCV; as received), the mean value for chlorine content (dry basis) and c) the median and 80th percentile values for mercury content (as received). Each one of the examined property is divided into five classes by limit values and thus the 125 SRF classes are "developed". Table 2 presents typical SRF properties [9,10,13,15].

Table 2. Typical Ranges of SRF Properties (source [10, 13, 15]).

Chemical Properties		Mechanical Properties	
Calorific Value *	3–45 MJ/kg	Particle size	10–300 mm
moisture	<25 % wt	Bulk density	120–300 kg/m^3
ash	<20 %		
Cl	<1.5 %		
Hg	<0.5 %		

*Depending on the type of SRF, while typical values are 12–25 MJ/kg

2.2. RDF and SRF Production and Utilisation

RDF and SRF produced from MSW through a number of different processes consisting in general of [9,10,12,13,15,23,24]:

- ✓ Sorting or mechanical separation
- ✓ Size reduction (shredding, chipping and milling)
- ✓ Separation and screening
- ✓ Blending
- ✓ Drying and pelletising
- ✓ Packaging and Storage.

Typically, the waste material is processed to remove the recyclable fraction (e.g. metals), the inert fractions (such as glass) and separate if it is possible the fine wet organic fraction (e.g. food and garden waste) containing high moisture and high ash material before being pulverised. The wet organic materials can then undergo further treatment such as composting or anaerobic digestion, and can be used as a soil conditioner for landfill restoration work or be landfilled. In some cases, the putrescible fraction is kept in place to enable the mass of material to be dried through biological treatment (the process of 'dry stabilisation') [10,12,13,15,23, 26].

The coarse fraction is either rejected or returned to the pulveriser. The medium fraction, consisting of paper, card, wood, plastic and textiles can either be burnt directly as coarse fuel or dried and pelletized into dense RDF. The decision as to whether or not to pelletize is usually based upon the location of the RDF manufacturing facility relative to the combustion facility. Figure 2 presents an indicative diagram for the production of RDF from source separated MSW [10,12,13,15,23].

There are two basic MSW methodologies which have been developed to produce high calorific waste derived fuel, RDF or SRF depending on the quality [9,10,12,13,15,23]:

- ✓ Mechanical Biological Treatment plant and
- ✓ Biological Drying Process.

In a mechanical biological treatment plant (MBT), metals and inerts are separated out and organic fractions are screened out for further stabilisation using composting processes, either with or without a digestion phase. It also produces a residual fraction which has a high-calorific value as it is composed mainly of dry residues of paper, plastics and textiles. Tables 3 and 4 present the SRF/RDF production and composition from MSW in selected EU Member States, respectively [9,10,12,13,18,19,27].

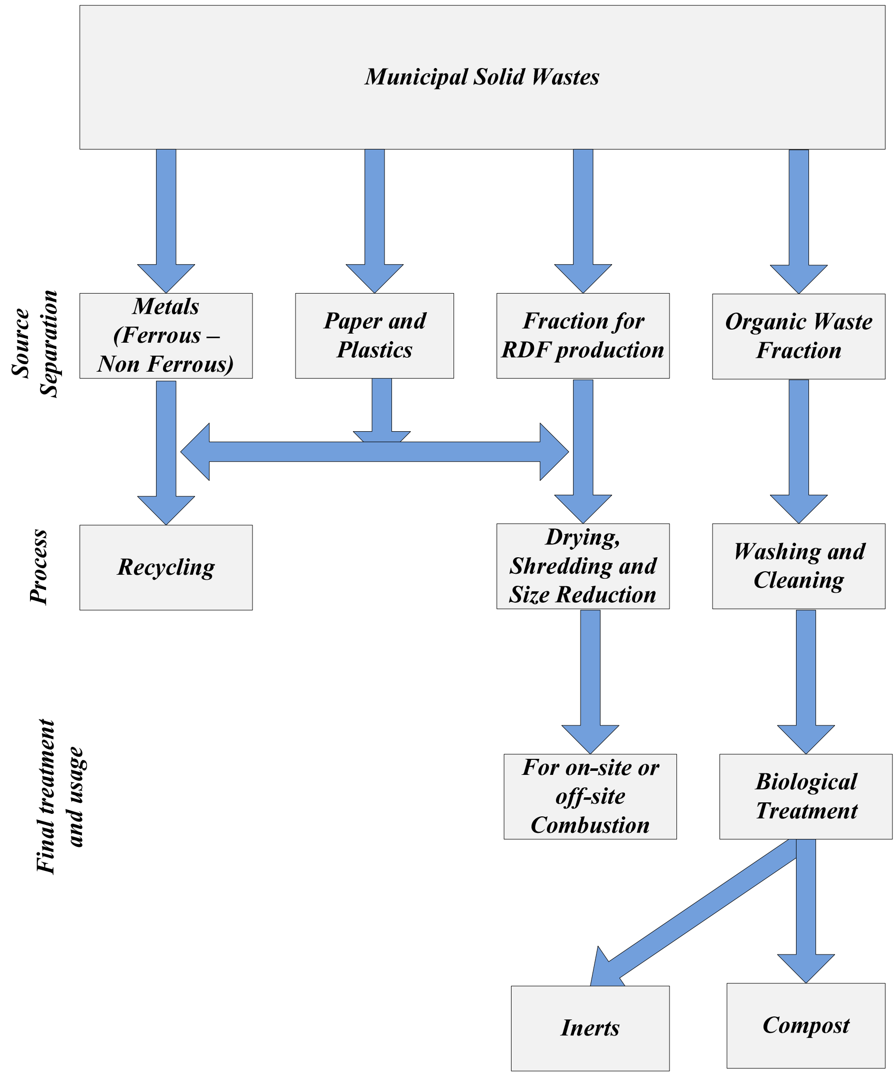

Figure 2. Schematic diagram for RDF production from source separated MSW.

RDF and SRF can also be produced through a 'biological drying' process, in which residual waste are effectively dried (and stabilised) through a composting process, leaving the residual mass with higher calorific value and suitable for combustion. The inerts and metals are removed through mechanical process before or after the bio-drying depending of the technology applied for bio-drying. Figure 3 shows the typical steps of this procedure [10-14, 20, 23, 26, 27].

Common to most RDF and SRF production concepts is a certain degree of size reduction and removal of organic and inert material. As a result, RDF has, on average, higher heating value, lower ash content, and a lower bulk density compared to untreated waste. Note that the majority of pollutants such as chlorine, sulphur and heavy metals are not affected by the pre-treatment, even though the metals removal systems minimize the present of metal in the produced fuel. Wide variations in the properties and composition of RDF and SRF even when it is produced by one particular system have been observed and the term seems to cover at least as wide a variety of fuels as the term 'biomass' [10-14, 23, 27].

Table 3. SRF production from MSW in selected EU Member States (source: [13]).

Overview SRF Production	year	Number of SRF-production plants	SRF kt/a	Cement kt/a	Power plant hard coal, lignite kt/a	CHP kt/a	MSWI kt/a	Export kt/a
Austria	2011		580	230	0	250		100
Belgium	2010	8	465	150				-
Finland	2010	>30	700	60	35	450	300	
France	2011	10	200	100		100		−50
Germany	2010	>100	6,150	1,900	750	3,500		0
Ireland	2009		200					10
Italy	2010		830	150				0
Netherlands	2010	>5	120	30	0	40	10	
Poland	2009		590	850				
Spain	2011	7	224	224				0
Sweden	2010		280	60		430		−210
UK	2009	14	765	200				70
EU 27			12,000					

Note: SRF in this table only concerns fuel derived from high calorific fraction of MSW, bulky waste, mixed commercial waste and from production specific wastes. SRF derived from waste wood, tyres and sludges are excluded from this table.

Table 4. RDF composition (typical) from different EU regions, (source: [11-13,29-31,38]).

Waste Fraction	Greece MBTC Plant (%)	UK (%)	Italy (%)	Flemish Region Sorting Process (%)	Flemish Region MBT (%)
Printed material	37.0				
Remaining Papers	6.60	84.0	44.0	13.0	64.0[a)]
Printed packing	18.10				
Plastic packing	22.90	11.0	23.0	31.0	9.0
Remaining plastic	1.70				
Textile	10.80		12.0	14.0	
Wood	0.40	5.0[c)]	4.5	12.0	27.0[b)]
Organic -others	1.30		16.5	30.0	

Notes: a) Includes paper, textile, wood; b) Includes rubber, synthetic material; c) Includes glass, wood, textiles and metals

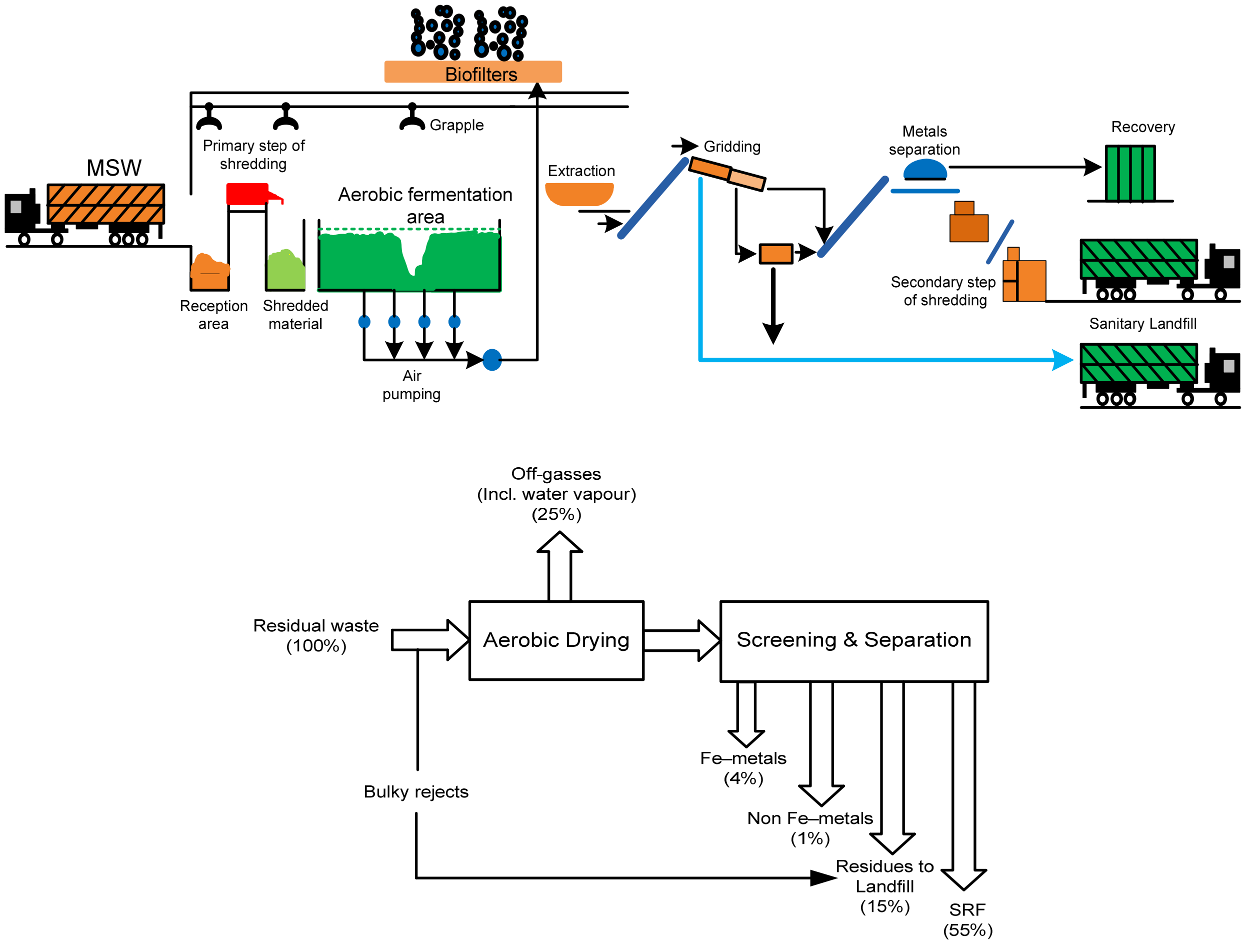

Figure 3. Schematic diagram for SRF production including mass balance) through biodrying process (source [27]).

The production of RDF and SRF, from household and business waste has grown from 2000 to 2005 from 1.4 million to 12.4 million tons/year as shown in Figure 4. Up to the year 2007 the total amount of RDF produced in Europe can be estimated to 15×10^6 t/y, approximately. The RDF is a fuel with very diverse qualities therefore needs to be handled in different ways. Table 5 compares SRF from MBT process of MSW with typical fossil fuels [13,16,18,25,27-31]. The production of steam and/or electricity can be done in power plants or specially designed fluidized bed reactors. Also, RDF can be used to produce cement, asphalt or bricks. Every application demands a different quality in the RDF production. Chlorine and heavy metals are limiting factors, but already these fuels are in use for energy production in many sectors, including power generation and cement industry, in EU (Table 3) and around the world [13,16,18,25,27,32-34].

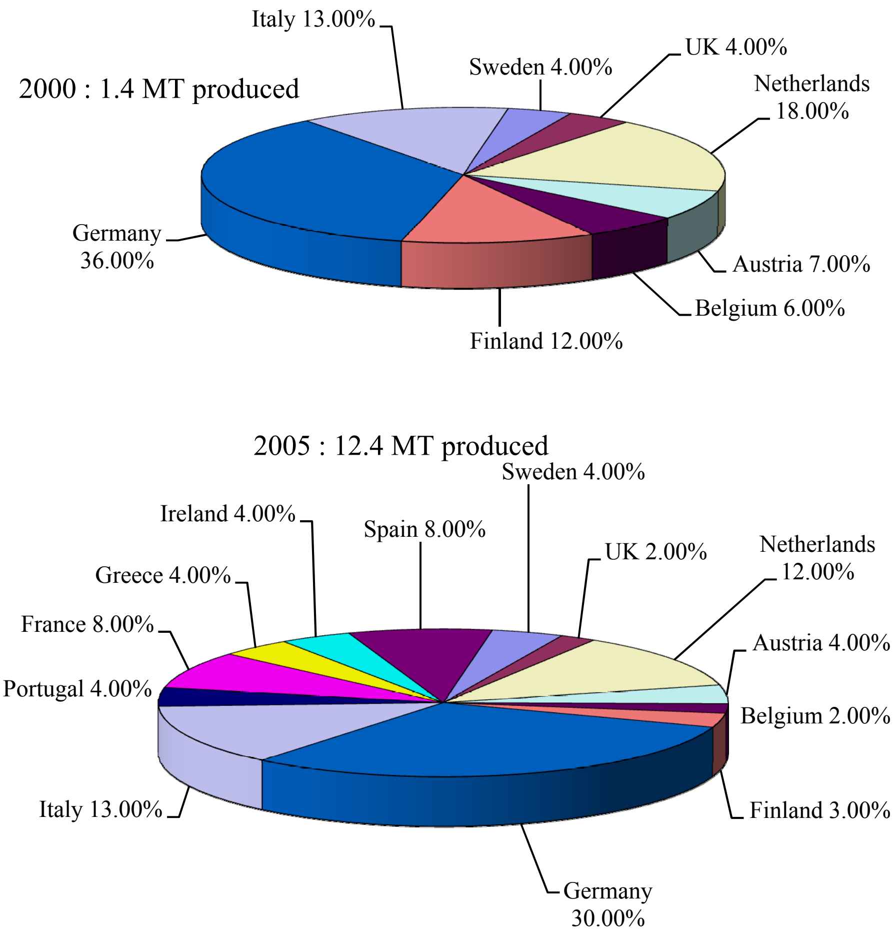

Figure 4. Projected growth in RDF / SRF production volumes, selected EU countries, 2000 – 2005 (source [11-13,29-31]).

Table 5. Comparison of CO_2 emissions from the use of fossil fuels and Secondary Derived Fuel produced by processed MSW in MBT process(source [13, 16, 18, 25, 27-31]).

Fuel Type	Calorific Value MJ/kg	Total CO_2 emission g CO_2/kg	Renewable energy content % renewable	CO_2 emission loading Mg CO_2 / TJ
Lignite	8.6	955	0%	111
Pit Coal	29.7	2,762	0%	93
Heating Oil	35.4	2,620	0%	74
Natural Gas	31.7	1,775	0%	56
MSW	8–9	1,170	50.0%	45
SRF from MBT	14–18 15 aver.	1,067	66.8%	24

According to several studies carried out around the world, the following options for the utilisation and conversion of RDF and SRF from MSW to energy have been already used or could be used in the future: [9,12,13,16-21,29,30,35-37]

- ✓ on-site in an integrated thermal conversion device, which could include grate or fluidised bed combustion, gasification or pyrolysis
- ✓ off-site at a remote facility employing grate or fluidised bed combustion, gasification or pyrolysis
- ✓ co-combustion in coal fired boilers
- ✓ co-incineration in cement kilns
- ✓ co-gasification with coal or biomass.

The total quantities of RDF from processed MSW used in Europe in dedicated waste to energy installations, in power generating plants, district heating plants and industrial processes such as paper mills and cement kilns has been estimated to amount to more than 2 million tonnes per year in 2001. It was reported that it is not always possible to secure an outlet for RDF and in Germany for example, quantities have to be stored. The quantities of RDF burnt are expected to increase in the future with planned increased capacity for RDF utilisation mainly in Belgium, Italy and in the UK. There are also plans for using RDF from MSW in other processes such as gasification and pyrolysis [10,13,16,18,19,21,31,36].

Germany is a representative example supporting the above. Currently, a total of 6.15 million tonnes per year of high calorific waste (i.e. calorific value > 11 MJ/kg) is available in Germany. Part of this is produced by MBT facilities, part of it concerns commercial waste. Nearly 1.9 million tonnes per year, mainly the fraction with a heating value in excess of 18 MJ/kg, is used for co-combustion in cement kilns and 750 kt in coal fired power plants. In addition, 3.5 million tonnes per year, with a heating value typically between 11 and 15 MJ/kg, are treated in Combined Heat and Power (CHP) plants. Long-term prognoses of the market volume show a small and gradual decrease towards 2020 even though it was increasing until 2010 [9,10,13,18,20,21,31,36,37].

Here, it must be stressed that co-incineration of waste in plants that were not designed to incinerate waste should not be allowed to cause higher emissions of polluting substances in the stack gas of such operations than those permitted for dedicated incineration plants [6,10,15,18,20,24,31-34]. Based on the composition of RDF /SRF these fuels contain pollutants and heavy metals that are very rare if not present in lignite and coal, thus the utilisation in coal or lignite fired power plants could result to higher emissions and, therefore, the power plants should be equipped with adequate Air Pollution Control (APC) systems able to minimise these pollutants [24,31-34].

From an energetic point of view, the waste conversion into RDF seems not be advantageous in terms of overall efficiency of the whole WTE process, when dedicated power plants are considered and no other possibilities for utilisation exists e.g. cement kilns, co-utilisation in existing coal power plants. In fact the energy required for the MSW pre-treatment is not compensated by an increase in the RDF combustion/gasification efficiency, as compared to the grate furnace or fluidised bed combustion of the MSW as it is [22,26,32]. This have been already demonstrated in literature were specific data from existing facilities regarding mass balances and energy demand in each step of SRF/RDF production for a specific facility are presented [22,26].

3. Potential Role of RDF and SRF in Hellenic Power Sector and Emissions Reduction

3.1. Waste management and RDF – SRF production in Greece

MSW production in Greece is increasing over the years, as everywhere in the world. Figure 5 presents this growth as it is officially announced by the Ministry of Environment, Physical Planning and Public Works and it was updated by more recent data. A constant increase in all the previous years is observed, even though after the crisis with smaller rates (years 2011 and 2012), and based on estimations this will continue in the coming years. The main portion of the produced quantities is concentrated in the Regions of Attica (39%) and Central Macedonia (16%), where Athens and Thessaloniki – biggest cities in Greece – are located. The composition of Greek waste is presented in Figure 6. It is similar to the European average while the differences exist in the organic fraction that it is higher and the moisture content that goes up to 40% [1,13,17,25,27,32,38,39]. The MSW management methodologies in Greece as they where applied on 2012 where landfilling for the 80.7%, recycling for 17.7% and composting for the rest 1.6% of MSW generated [39]. Here it must be mentioned that in Greece no MSW incinerators operate, while mechanical treatment units, producing RDF/SRF, today either started operation at the ending of 2006 or are under construction [3,20,27,38-43].

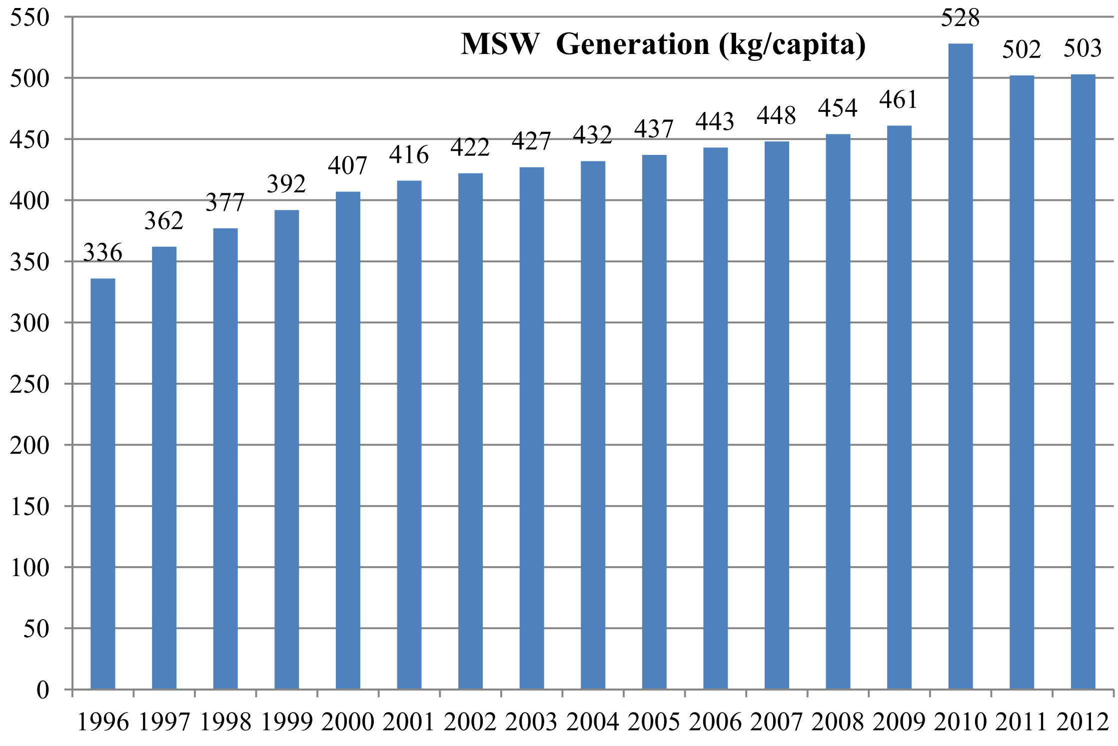

Figure 5. Municipal waste generation (kg/capita) in Greece from 1996-2012; (source: [39]).

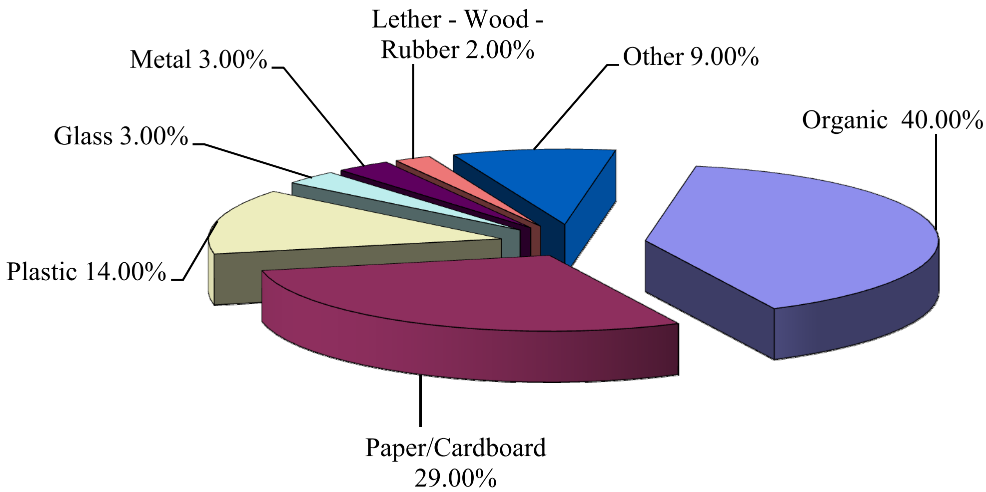

Figure 6. MSW composition in Greece; (source [27,38]).

In Greece, from November 2006 the MSW Mechanical Biological Treatment and Composting (MBTC) Plant at Ano Liosia (Attica) has produced 22,000 t per annum of RDF of 27.4% moisture, and Cl content of 0.4%, with a calorific value of 15.3 MJ/kg. Figure 7 presents the main composition of the produced RDF and Table 6 shows the input and output streams as where initially planned for the MBTC Plan in Ano Liosia. RDF/SRF represents the most refined fuel form that can be obtained from mixed MSW, as the source separation in Greece is increasing [20,27,38,40,41,44,45]. This fuel justified the investment of recycling plant and was projected to be financially advantageous to the conventional approach of mass-burning of solid wastes according to a study of Economopoulos [41, 42] presented in Technical Chamber of Greece. Nevertheless this fuel has very limited acceptability by the public, and very limited use is power generation [20,27].

According to the National Plan for Waste Management as published by the Greek Ministry of Environment, Physical Planning and Public Works for 2007-2013 is foreseeing a number of Plants for RDF and SRF production in several areas of Greece. Table 7 gives the Regions/Prefectures where the RDF/SRF production plans are being foreseen, and their annual capacity. Here it must be mentioned that MSW Processing Plants with energy recovery have been included in National Plan for Waste Management also for the Regions of Western Greece, Thessaly, East Macedonia and Thrace, but no capacity or number or other details were available up to now. As it can been seen the potential production of SRF is quite high, especially in the cases of Attica and Central Macedonia Regions, were the expected quantities can reach up to 346.5×10^3 t/y and 132×10^3 t/y [27,41,44,45].

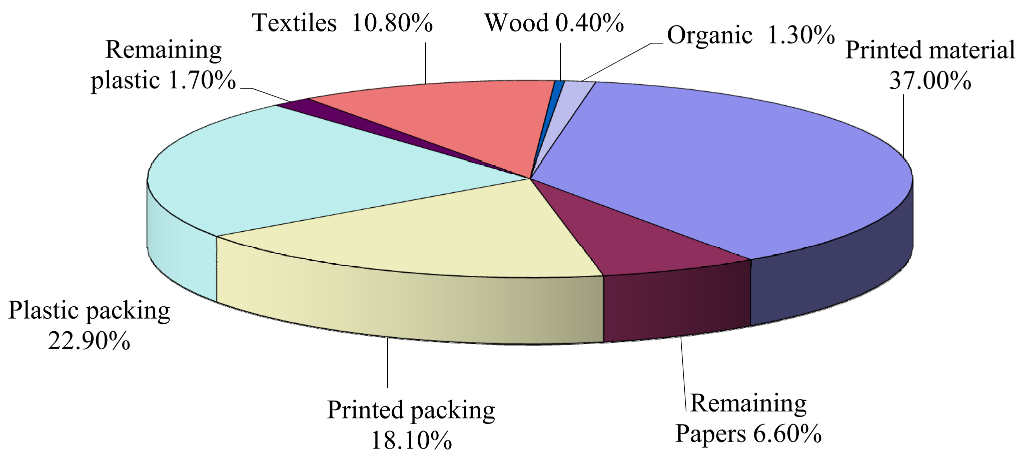

Figure 7. Mean composition of the RDF produced at Mechanical Biological Treatment and Composting Plant (MBT) at Ano Liosia, Athens Greece (source [27,38]).

Table 6. Input and output streams as per initial design of plant and average composition of RDF produced at Ano Liossia MBTC Plant in 2006-2008 (source [27,38,45]).

Input Stream		Output Stream		RDF Mean Composition	
Materials	**Quantity (t/day)**	**Materials**	**Quantity (t/day)**	**Materials**	**Quantity (%)**
MSW	1,200*	Compost	300	Printed Paper	37.80
Sewage sludge	300	RDF	360	Other Papers	4.90
Green wastes	130	Fe	35	Paper packing	16.50
		Al	5	Plastic packing	26.20
		Wastes	330	Other plastics	1.30
		Water	500	Textiles	11.00
		Volatiles	100	Wood	0.40
				Organic	0.80
				Impurities (Incombustibles)	~1.10

*at present, the MSW feed to this plant is reported to be 700 tons/day.

Table 7. Foreseen Plants for MSW treatment and SRF/RDF production in Greece based on the approved Municipal Solid Waste Management Strategic Plan of the Greek Ministry of Environment, Physical Planning and Public Works.

Regions / Prefectures		Plants	Waste Quantities ($x10^3$ t/y)	SRF Quantities ($x10^3$ t/y)
Attika		MBTC I	495	148.5*
		MTBC II	660	198.0*
Central Macedonia	NW Thessaloniki	MBT	180[1] 180[2] 360[3]	54[w]
	SA Thessaloniki	MBT	120[1] 180[2] 240[3]	36[w]
	Serres	MBT	90[1] 90[2] 100[3]	27[w]
	Imathia	MBT	50[1] 55[2] 60[3]	15[w]
	Pellas		30[2] 35[3]	9[w,w]
	Pierias		30[2] 35[3]	9[w,w]
	Kilkis		35[3]	10.5
West Macedonia		MBT	150[#] 106[#]	19.5
Peloponnesus			255	76.5
Crete	Chania	MBT	70	+
	Iraklio ¦	BioDry	70 210	35

Notes: The quantities have been calculated with factor 0.3 based on existing MBTC Plant operating in Ano Liosa, unless another quantity is calculated in the following notes or written in the table.

* : 120×10^3 t/y in MBTC I and 160×10^3 t/y in MBTC II of sewage sludge while be treated also.

[1],[2],[3] : planned quantities for the years 2010, 2013, 2020 respectively

[w],[w,w]: The quantities have been calculated for the years 2010, 2013 respectively

[#] : 150×10^3 t/y is the scheduled capacity, 106×10^3 t/y is the foreseen processed quantity for 2011 and the SRF production rate is around 18%.

¦ : In Iraklio, Prefecture of Crete a Bio-drying Plant producing SRF with approximately 50% SRF in the output stream is planned with capacity 70×10^3 t/y, in the future will reach 210×10^3 t/y.

3.2. Potential for RDF – SRF utilization in the Hellenic Power Sector and emissions reduction

Based on international experience, either the utilization of the foreseen produced RDF - SRF in Power Sector can be as co-combustion or co-gasification with lignite on the existing facilities, or utilization in a dedicated power plant [18-21,31,36]. In the case of co-combustion and co-gasification of SRF with lignite significant research have been developed already including also the Power Plants of West Macedonia. The results of two European Projects are supporting the possibilities of co-combustion and co-gasification. Extended experimental results during these projects have demonstrated the possibility to substitute a part of lignite with SRF without actual affects in the operation or the emissions of the power plants, and usually low investment cost. Based on the results of these Projects, researchers involved have already demonstrated this possibility. One important parameter is that among the researchers two of them were NTUA - Laboratory of Steam Boilers and Thermal Plants and Institute for Solid Fuels Technology and Applications in Ptolemais, which are among the experts used by Power Producing Companies in Greece. In their work have experimentally proven that the SRF quantities similar to the ones that will be produced in West Macedonia, can be utilised in Kardia's Power Plants in order to substitute 2–3% of lignite in one of the three 300MW Units. These researchers proposed also the same scenario for the SRF production in Peloponnesus for Megalopoli III Thermal Power Station. Here it must be mentioned that a new Desulphurisation Unit (FDG Plant) is under construction in Megalopoli III Thermal Power Station, it is in the phase of equipment installation, which will reduce the GHG emission from the Power Plant [16-18,29,30,35,45].

Here it must be stressed out that the co-combustion of waste in coal or lignite fired plants could cause significant corrosion, mainly due to Chlorine and other corrosive content arise from the burn of RDF/SRF in high temperatures. Several studies have shown that the substitution ratio should not exceed 15–20% depending on the quality of the SRF/RDF. In case that the SRF/RDF present low quality and high chlorine content the substitution should not exceed 10% [37,33,46-49]. Experiments executed in existing lignite fire plants in Greece were performed with only 2-3% replacement and the results showed that in such small substitution figures the corrosion effects are inside the accepted limits [16-18,29,30]

Nevertheless the possibility for toxic emissions from co-combustion exists due to the wastes composition. Presumably, most of the objects that contain volatile metals will be removed during the RDF preparation process. An analysis of the RDF produced at Ano Liosia has shown that it contains very low concentrations of these metals [38]. However, the typical MSW contains 0.5% chorine, half of which derives from organic wastes and salt, and half from chlorinated wastes. Recent works showed that the RDF produced from MSW in Greece will contain almost the same concentration of chlorine [38]. Even very small concentrations of chlorine lead to the in-situ formation, during cooling of the combustion gases, of the toxic compounds that are called dioxins and furans. All modern WTE plants are equipped with activated carbon injection (ACI) so that any volatile metals or dioxin/furans molecules in the process gas are attached to the carbon particles and are then removed from the gas stream in the subsequent fabric filter baghouse. The final concentration of dioxins/furans in the stack gas must be, according to EU and US regulations be less than 0.1 Toxic Equivalent nanograms per standard cubic meter. The EU and US WTEs plants emit less than 0.03TEQ ng/Nm^3. Therefore, lignite power plants that will co-combust RDF must be equipped with ACI and fabric filter baghouses [5,22,24,31-33,43,46-50].

Based on the above it is proposed to utilise the SRF productions in West Macedonia and Peloponnesus in the nearby Thermal Power Stations (equipped with adequate Air Pollution Control systems). Following this scenario and the results of the Projects indicating that 1kg of lignite can be substituted by 1kg of SRF and at the same time 1 kg CO_2 emissions/kg SRF can be prevented, the results could of co-combustion and/or co-gasification will be 20×10^3 t/y of lignite saved and 20×10^3 t/y of CO_2 avoided in Western Macedonia, 76×10^3 t/y of lignite saved and 76×10^3 t/y of CO_2 avoided in Peloponnesus [16-18,20,29,30,35].

But these calculations can be considered draft as not all the SRF can be considered as renewable. A more precise calculation based on the literature and the findings of these projects the calculations are changed as follows:

- ✓ Emission of fossil CO_2 by lignite: 955g fossil CO_2/kg (Table 5)

- ✓ SRF is considered 67% (Table 5) Renewable thus from the 1067 g of CO_2 emitted by the combustion of 1kg SRF only the 110%-67% = 33% can be considered as non renewable resulting in 352.11 gr of fossil CO_2/kg SRF

If the substitution will be based on the analogy 1kg SRF will replace 1kg of lignite then the reduction of fossil fuel will become: 955 g fossil CO_2/kg lignite – 352.11g fossil CO_2/kg SRF = 602.89 g fossil CO_2/kg of fuel. In that case the substitution of 1kg of lignite by 1kg of SRF will result about 603 g of CO_2 emissions reduction.

Thus, the reductions mentioned above based in literature for the cases of Western Macedonia and Peloponnesus will be then 12.06×10^3 t/y of CO_2 avoided and 45.83×10^3 t/y of CO_2 avoided in Peloponnesus, respectively.

For the case of Crete a dedicated utilisation plant is foreseen in the National Plan for Solid Waste Treatment. The quantities foreseen after 2010 are in the average of the dedicated plants as they are 105×10^3 t/y. Based on the international experience, such a plant could provide at least 69.7GWh$_e$, assuming that 1t SRF provides to the grid 700 kWh$_e$, in the island of Crete covering a significant part of electricity needs. Since the island of Crete is using heavy oil and diesel oil power stations to cover the electricity needs this utilisation will directly resulted in significant emissions reduction [18,20,27,32,41,43,45,50].

The cases of Attica and Central Macedonia are complicated due to the public acceptance. The quantities are quite high and thus based on international experience the best method for utilisation is the dedicated plants in each region. Following the same assumption as above, that 1t SRF provides to the grid 700 kWh$_e$, the production of electricity would be at least 238 GWh$_e$ and 92.4 GWh$_e$, for Attica and Central Macedonia respectively. Based on the fact that because of the small distance that these power plants will have from the consumers (Athens and Thessaloniki) the benefit is even higher due to lower network losses from the construction of these plants. In addition a significant volume of wastes will be treated in a way that reduces their volume, reducing the landfilling requirements for waste management. The benefit is quite high both in electricity supply and to the environment, in these regions which facing continuous problems there [18,20,27,32,41,43,45,50]. In addition these facilities will result in less power from fossil fuel power stations (Gas-fired plant of Lavrio). Here it must be notice that in the case of Central Macedonia the proximity with the power stations in Western Macedonia and the ecxisting railway connection can provide the alternative low cost solution of utilisation as substitute of lignite in the existing facilities. Then an additional 160×10^3 t/y of lignite can be saved and 96.5×10^3 t/y of CO_2 could be avoided in Western Macedonia [16-18,20,29-32,35,37].

These plants based on the fact that 0.603 kg CO_2 emissions/kg SRF can be prevented, can reduce the GHG emissions of the Power Generation Sector by a significant number of MtCO_2 and reduce the dependency from imported fossil fuels, supporting the efforts for economic growth of Greece. These additional benefits to the ones for environment prove that the utilisation of RDF/SRF for energy production will provide with significant benefits not only to the environment but also to the economy and the Power Generation Sector in Greece [16-18,20,21,27,31,32,35,37,38,43,51].

The utilization of RDF/SRF in dedicated plants and in co-gasification /co-combustion in the existing lignite fired power plants was investigate recently in a recent paper of Samolada and Zabaniotou [20]. This work is using swot analysis to investigate the subject in Greece and Cyprus but also considering the potential utilisation in cement kilns. The authors of this work evaluate the possibilities considering only dedicated plants and cement kilns considering the efficiency and public acceptance. Nevertheless their SWOT analysis does not consider the lack of information to the public and the major misinformation that exists in the Greek community for waste to energy facilities as a significant part of problem. On the other hand the Hellenic cement companies have accepted to utilise RDF/SRF of a very specific composition that is very costly to be achieved from SRF/RDF produced from mixed MSW. That is the reason the cement industry utilises waste derived fuel produced from specialised industrial wastes and waste tyres. The SWOT analysis is not considering the fact that the cement industry is facing significant reduction in cement production due to economic crisis, even though it demonstrates the limited capacity to absorb the existing and foreseen capacity after the completion of the aforementioned waste management facilities around Greece. Thus the required investments to absorb the existing and foreseen production of the on going waste management projects seems unrealistic. On the other hand the already produced SRF/RDF from MSW was not accepted for utilisation in the existing cement kilns and it is land filled [16-18,20,27,35,38,43,45].

One significant point that seems to help the utilization for power production is that the lignite exists in Greece presents rather lower LHV (lower heating value) than hard coal and SRF/RDF and the lignite fire plants usually mixed it with hard coal and biomass of higher LHV. This potential has been already investigated and the viability has been proved also from energetic point of view in EU and in the Hellenic Power industry in the basic types of power plants, which is very important parameter [16-19,22,26,29-31,35,37,45,50]. In addition Greece is importing a significant part of energy sources such as natural gas and coal and the utilization of SRF/RDF will support the reduction of these imports with notable benefits for the local energy industry, employment and of course the economy [51]. Thus even though from energetic point of view the utilization in cement kilns seems to present more advantages, the utilization for power production in dedicated plants seems to provide significant benefits as it is already mentioned.

4. Conclusion

Waste derived fuels from MSW in the forms of RDF and SRF are produced in EU following the continual European stringent environmental standards towards an effective environmental protection and sustainability. The recent European policy on wastes reflects the continual increase of the public awareness in environmental issues. The effective and sustainable MSW management is a hot environmental issue. The careful selection of the treatment processes is of primary importance both from the economical and the environmental point of view. To this respect, SRF production from municipal solid wastes and the like streams should be second step after the application of extensive source separation, collection and recycling of the recyclables and composting of the organic part. The amounts of SRF utilised in EU prove the contribution of this fuel in many energy intensive sectors such us cement industry and power production.

Even though in EU a significant amount of SRF/RDF is utilised in cement kilns with proven benefits, the Greek cement industry cannot utilised the existing and foreseen volumes to be produced. On the other hand there are no waste-to-energy facilities to utilise it. Thus the only remaining option for Greece except export are the utilisation of SRF/RDF in dedicated power plants and as substitute fuel in the existing lignite fire power plants.

The perspective to use SRF as substitute fuel in brown coal power plants with adequate Air Pollution Control System or in dedicated power plants provides significant benefits. The current situation, the waste potential and National Plan for Solid Waste Treatment in Greece showed that high quantities will be produced that should be utilised. Results from several research works published up to now, have proven that a significant part of these SRF/RDF quantities could be utilised in the existing power plants of Macedonia and Peloponnesus. On the other hand the vast quantities expected in the areas of Athens and Thessaloniki seems to need dedicated power plants, in order reduce the transportation costs. In Crete a dedicated power plant is foreseen that could utilised the foreseen SRF/RDF production of the island. Significant environmental benefits would be brought in that way, such as the savings of solid fuels, reducing the dependency of import fuels, reducing the CO_2 emissions of the Power Generation Sector and the avoidance of landfilling, as many studies have shown. Based on the results up to now even though the SRF production will not reach the aforementioned volumes the SRF should be considered as a fuel by the Greek Power Generation Sector.

Conflict of Interest

All authors declare no conflicts of interest in this paper.

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