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Geothermal Energy Development in Spain - Country Update Report

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ABSTRACT

Geothermal resource exploration, assessment and evaluation started through Spain in the seventies with a general geological and geochemical survey of known thermal springs and areas showing signs of thermal activity. The most interesting sites were then selected, based on geological criteria and the findings of the survey mentioned above. Over the following decades, each of the selected areas has been investigated utilizing techniques from geology, geophysics, geochemistry and related disciplines, the intensity of the investigation depending on each area's geothermal potential. Lastly, deep drilling has been done, enabling the geothermal potential of the more important areas to be evaluated. These major areas are located in the southeast (Granada, Almería and Murcia), northeast (Barcelona, Gerona and Tarragona), northwest (Orense, Pontevedra and Lugo) and center (Madrid) of the Iberian Peninsula. Other, more minor areas located in Albacete, Lérida, León, Burgos and Mallorca have also been investigated.

The geothermal resources evaluated in all these cases exhibit low temperatures, 50-90 ºC. The only area where high-temperature fluids might possibly exist at depth lies in the volcanic archipelago of the Canary Islands. Hot dry rock resources have been evaluated on the islands of Lanzarote and La Palma. On the island of Tenerife, the presence of high-temperature areas has been investigated, but no commercially viable geothermal reservoirs have been found.

Low-temperature geothermal sites are currently being exploited on a small scale. For example, geothermal fluids are being used for heating and to provide hot water to spa buildings in Lugo, Arnedillo (in La Rioja), Fitero (in Navarra), Montbrió del Camp (in Tarragona), Archena (in Murcia) and Sierra Alhamilla (in Almería). In Orense and Lérida, geothermal waters are being used to heat homes and schools. Greenhouses are being geothermally heated at Montbrió del Camp (Tarragona), Cartagena and Mazarrón (in Murcia), and Zújar (in Granada); these facilities cover a total area of over 100,000 m^2.

1. INTRODUCTION

The geothermal resources exploration started in Spain in 1974 with a “General inventory of geothermal indicators” made by Instituto Geológico y Minero de España (IGME), that is a equivalent of a Spanish geological survey. IGME is the principal organization engaged in research and development of geothermal energy in Spain. The last project developed has been the “Geothermal investigation in Mallorca (Balears Island)”, in 2002. From 1974 until today IGME has carried out more than seventy projects in order to explore and assess geothermal potential of the spanish subsoil. Between 1979 and 1988, ENADIMSA a public company of the Ministry of Industry for mining research an development, are engaged in the evaluation of geothermal resource by means of deep investigation well and feasibility studies. From 1986, different organisms from the Regional Autonomous Authorities and European Community became actors of the geothermal energy resources evaluation and exploitation. The last nineties, this investor effort decline and the only organisation that remain active is the IGME.

2. GEOLOGY BACKGROUND (FIGURE 1)

The Variscan Iberian Massif extends over the western and northwest part of Spain and is made up mainly of old metasediments and granitic rocks. The other regions to the E and S comprise three main Alpine chains (Pyrenees, Betic and Iberian ranges) and Tertiary basins (Duero, Tajo, Ebro and Guadalquivir). The postorogenic extension in the Mesozoic formed the Atlantic margin, while the Neogene one produced Mediterranean margins. Neogene extension was usually accompanied by a significant amount of volcanism (Gerona, Ciudad Real, Murcia and Almeria).

Deep seismic data acquired in the northern and southern Variscan Massif constrain the crustal and lithospheric structure in theses regions. The regional thermal regime in the eastern part of Spain is clearly affected by lithospheric thickness variations related to the Alpine and Neogene tectonic events as can be seen on the heat-flow density map.

Geothermal manifestations in Spain are found in a variety of geological settings. Most of the thermal springs are associated with faults and rough topography at mountain ranges or basin flanks. Some of them have been specifically investigated from the geothermal point of view. Other areas of geothermal interest have also been identified on the basis of oil prospection data and other sources. Particular attention has been paid to basin structures and especially to Neogene extension basins associated with the Catalan Coastal Ranges in NE, or with intramountains Betic Ranges. Specific research has been made in the active volcanic area of the Canary Islands where a high enthalpy reservoir may exist.

3. TEMPERATURES (FIGURE 2)

Generally, water and mining exploration boreholes are not more than 300 m deep, providing information only on the shallow temperature field. Therefore, temperature maps were based mainly on the deeper oil borehole data. Because of the scarcity of deep exploration boreholes in the Variscan Massif, most of the temperatures data are restricted to the eastern half of Spain.

Local thermal anomalies can be observed on the temperature maps in the southwestern Valencia though and Ebro platform, eastern Betics (Almería), northern Ebro

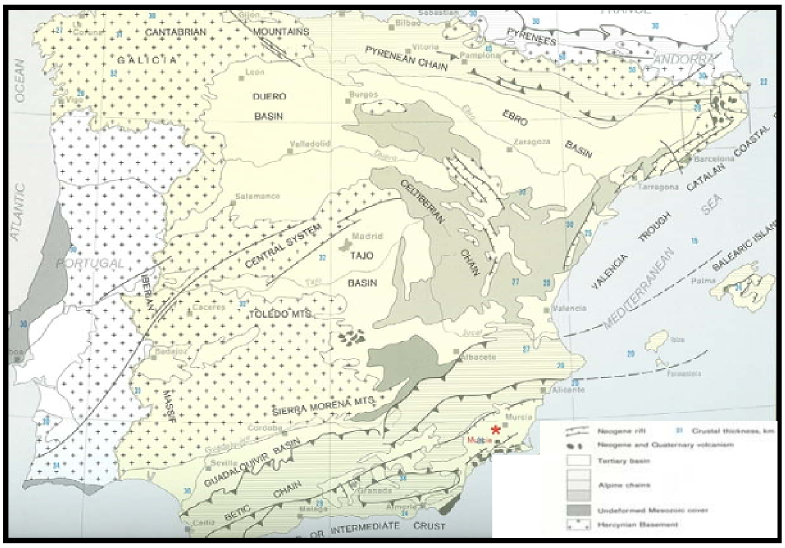

Figure 1: Geological-geothermal thematic map

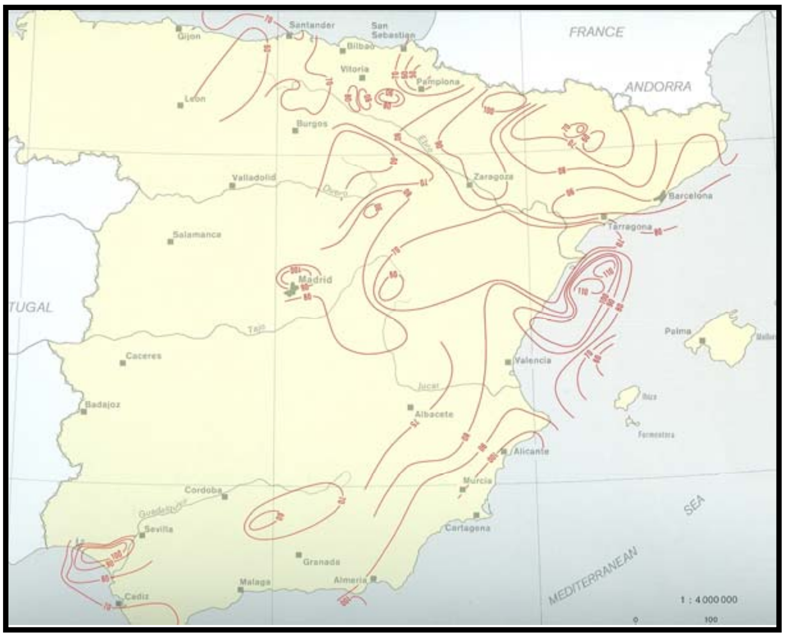

Figure 2: Temperature map at 2,500 m

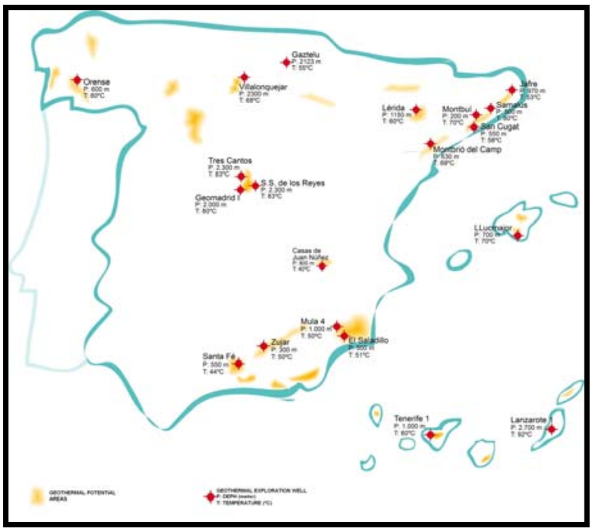

Figure 3: Geothermal potential areas and geothermal investigation wells

basin, and the Basc-Cantabrian basin. These anomalies can be traced down to 2,500 m depth.

No maps could be compiled for the Balearic Islands and the Canarian Archipelago due to the lack of deep wells.

4. MAIN POTENTIAL GEOTHERMAL RESERVOIRS (FIGURA 3)

The following potential geothermal areas are selected like reservoirs of special interest:

4.1 Galicia (Northwestern Variscan Massif)

The known geothermal reservoir is constituted by cataclastic granitic wedges located in fracture zones where most geothermal areas are found. Temperatures are around 70 to 80 ºC, reached at depths of less than 500 m. Salinity of the water is less than 1 g/l and productivity is very high in fractured zones.

4.2 Ebro basin

In this basin, the foreland of the Pyrenee chaine, several geothermal possibilities are found:

Vitoria-Treviño: Cretaceous limestone at depths of 2,000 m with temperatures ranges between 40-60 ºC.

Huesca: Geothermal reservoirs are found in Jurassic formations of calcareous-dolomitic nature at depths of 2,000 to 3,000 m with temperatures above 90 ºC.

Lerida: In this area reservoirs have been found in calcareous and detrital Triassic rocks located at depths less than 1,500 m. Temperatures are around 60 ºC and salinity is 3 g/l.

4.3 Catalan Coastal Range

Different extensional grabens with significant geothermal manifestations can be distinguished in the northeast of Spain:

Valles-Penedes Graben: This basin is bordered by two main faults and is filled with Miocene deposits reaching depths of 3,000 and 1,000 m at the NW and SE borders respectively. The geothermal reservoir has been identified at the NW master fault and it is constituted by a cataclastic granitic zone. The temperature is about 90 ºC and the salinity ranges between 0.5 and 3 g/l.

La Selva Graben: Located at the NE end of the Valles-Penedes Graben it has characteristics similar to those of the Valles-Penedes.

Ampurdan Graben: This Tertiary basin is filled with a thick sedimentary sequence of more than 2,500 m. Allochthonous calcareous lenses (Eocene) represent excellent geothermal aquifers at an average depth of 1,000 m. The temperature is about 50 ºC and the salinity is close to 5 g/l.

Olot Graben: The basement outcrops in the southern part of this basin and dips down to 3,000 m to the north. The geothermal objective is the Early Eocene limestones formation which has a thickness of 200 to 400 m buried under a cover of 1,000 to 3,000 m of evaporites and detrital deposits.

4.4 Betic Cordillera

This area includes several basins: Granada, Lanjaron, Guadix-Baza, Almeria, Mula, Mazarron, Cartagena, Guadalentin and Lluchmajor (Mallorca). These basins are generally filled with Tertiary sediments overlying allochthonous carbonate formations of considerable permeability although with a very complex structure. Different prospections have identified geothermal reservoirs at depths of less than 1,000 m. Temperatures are in the range of 40 to 50 ºC and salinities are moderate (less than 2 to 3 g/l).

4.5 Others areas

Albacete-Cuenca (SE of Madrid): In this area reservoirs are located in Mesozoic carbonates at depths of 1,400 to 2,000 m and temperatures ranging between 70 and 80 ºC.

Guadalquivir Basin: The main geothermal objective in this basin, is the Jurassic dolomite formation found at 1,500 to 2,000 m with temperatures of 50 to 80 ºC.

Salamanca-Caceres: Here the geothermal reservoir is constituted by granite and/or Palaeozoic rocks in fracture zones.

Iberian Chain: Geothermal reservoirs are found at the borders of the chain, particularly in Jurassic limestones with temperatures close to 50 ºC.

4.6 Canary Islands

The Canarian Archipelago is constituted by volcanic islands located at the limit of the continental margin and oceanic basement. In the island of Gran Canaria some geothermal reservoirs are found at depths of about 1,500 m with moderate temperatures of 50 to 70 ºC.

In the southern part of the island of La Palma and in the western part of Lanzarote very hot dry rocks at shallow depths have been found. In the central part of Tenerife Island, the existence of a very high temperature reservoir is being investigated.

5. PRESENT ASSESSMENT OF RESOURCES IN MOST KNOWN AREAS

5.1 Subijana limestones, Vitoria-Treviño

This area, located at the NW extremity of the Ebro basin, offers a reservoir made up of Cretaceous limestone (Subijana limestone). This formation is located at variable depths, generally less than 2,000 m, with a thickness of 300 to 400 m. The temperature ranges between 40 and 60 ºC and the water has a salinity of less than 1 g/l. In the area of Vitoria-Treviño the information is based on hydrocarbon investigations (wells and geophysical measurements).

5.2 Cretaceous of Duero, Duero Basin

This large neogene basin was formed during the Tertiary and overlays a Mesozoic sequence which constitutes the main geothermal target. Geothermal reservoirs are located in some Tertiary sandstone levels, in calcareous and detrital Cretaceous deposits and in calcareous and dolomitic Jurassic formations. Tertiary reservoirs are found at depths less than 1,000 m with a temperature of 40 ºC in the neighbourhood of the city of Leon whereas the rest of the reservoirs are located at depths between 1,500 and 2,500 m with a temperature range of 60 to 90 ºC. In the Duero Basin information comes from a variety of investigations.

Although not many wells have yet been drilled, geophysical surveys allow a reasonable extrapolation to estimate the reservoir conditions.

5.3 Detrital Tertiary of Madrid, Madrid area

This Tertiary basin is made up of a thick continental sequence of 1,000 to 3,000 m overlying Mesozoic sediments. The main geothermal reservoir is located at the Miocene-Oligocene (basically detrital sandstones) level.

The most interesting area is located NNW of Madrid where the thickness of the geothermal aquifer is 100 to 500 m and the temperature reaches values above 90 ºC. The top of the geothermal reservoir in this area is highly variable within the basin. Transmissivity up to 40 Dm and salinity of 30-60 g/l are other important characteristic of this reservoir. Above this geothermal reservoir a number of shallows aquifers with temperatures below 40 ºC are also found and may be of interest.

Data from several boreholes and geophysical investigations are available.

5.4 Vega de Granada Basin

The Jurassic limestones is the main geothermal reservoir in the "Vega de Granada" basin. The available information includes data from a few geothermal and oil boreholes, many groundwater boreholes and a few geophysical surveys. The reservoir extends from 500-1,000 m depth, being 200-250 m thick. The limestones has a porosity of the order of 5-8%. The temperature of the aquifer is between 35-45 ºC and the salinity of the fluid is of the order of 3-4 g/l. Flow rates of 250 m^3/h is produced by well.

5.5 Campo de Cartagena Basin

Both the middle Miocene calcarenite and the Jurassic limestone, are the geothermal reservoirs in this area. The Campo de Cartagena basin is a structural graben in which several connected aquifers are present. The available data was aquired from hydrogeological and geophysical surveys and numerous groundwater boreholes. The Jurassic limestone extends from the surface to > 1,000 m depth and is 100-150 m thick. Salinity is 2-3 g/l and the porosity ranges between 6-9 %. The temperature in the aquifer is 25-50 ºC.

5.6 Ebro Basin (Jaca-Sabiñánigo Area)

In this area S of the Pyrenees, gas and oil prospection boreholes located an important geotermal reservoir in carbonate levels of Palaeocene-Early Eocene age. In addition to the data from these gas boreholes, geophysical surveys characterize the aquifer. This formation is found at a depth of 2,800-3,600 m and exhibits a thickness of 500-600 m. The calcareous deposits at the top of the reservoir grade into dolomites towards the bottom. The reservoir rocks have a porosity of 5-8 % filled with fluids of a salinity of 2 g/l. The temperature varies between 150-180 ºC.

5.7 Mula Basin

In the Mula basin, the middle Miocene calcarenite and the Jurassic limestone are connected hydraulically forming a single geothermal reservoir. The characteristics of this reservoir were defined by data from geothermal boreholes and geophysical surveys. The depth of the reservoir is variable, extending from 100-1,000 m. Total thickness ranges from 100-300 m in a few places. The rocks possess a porosity of 10% filled with fluids of 1 mg/l salinity. The temperature ranges from 30-70 ºC.

5.8 Guadalquivir Basin

This Jurassic limestones geothermal reservoir is well mapped by oil and salt exploration boreholes. The depth of the formation is variable ranging from depths of 300-3,000 m. Total formation thickness exhibits also great variations: 250-1,000 m. The porosity is about 16-19 % and the temperature lies between 50-75 ºC. In the eastern zone, where reservoir is deeper, temperature arise to 160 ºC.

6. PRESENT STATUS AND FUTURE PERSPECTIVE OF THE USE OF GEOTHERMAL ENERGY

Main exploitation project of low temperature geothermal energy at present is limited to greenhouses heating in the Mediterranean area (Murcia-Alicante and Tarragona). A few projects in Galicia and Lerida use geothermal energy for both domestic and school-heating.

Other projects are associated with thermal springs and balneological applications. The geothermal energy is mainly used to heat spa buildings.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity)

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2004	-	-	31,400	143,326	23,040	26,330	7,871	63,008	3,509 Biomass wind	13,191 Biomass wind	65,820	245,855
Under construction in December 2004	-	-										
Funds committed, but not yet under construction in December 2004	-	-										
Total projected use by 2010												

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT

AS OF 31 DECEMBER 2004 (other than heat pumps)

1) I = Industrial process heat; H = Individual space heating (other than heat pumps)
C = Air conditioning (cooling); D = District heating (other than heat pumps)
A = Agricultural drying (grain, fruit, vegetables); B = Bathing and swimming (including balneology)
F = Fish farming; G = Greenhouse and soil heating
K = Animal farming; O = Other (please specify by footnote)
S = Snow melting

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. Flow rate (kg/s)[inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.004184 (MW = 10^6 W)
or = Max. Flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. Flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (^{o}C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
Lérida	H	9	58	25			1.24	6	26.11	0.66
Arnedillo	H+B	11	50	30			0.92	8	21.1	0.73
Fitero	H+B	8	52	30			0.73	5	14.5	0.63
Lugo	H+B	4	44	25			0.32	2	5.01	0.50
Orense	H	5	75	30			0.94	4	23.74	0.80
Archena	H+B	10	48	25			0.96	6	18.20	0.60
Sierra Alamilla	H+B	8	52	30			0.74	5	14.51	0.62
Montbrió	H+B	15	42	18			1.50	10	31.65	0.67
Montbrió	G	6	78	25			1.33	3	20.97	0.50
Cartagena	G	150	38	18			12.55	60	58.26	0.40
Zújar	G	10	45	20			1.05	4	13.19	0.40
TOTAL							22.28		347.24	0.49

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES

AS OF 31 DECEMBER 2004

[1)] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184
Or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[2)] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3)] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1)] (MWt)	Annual Energy Use[2)] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3)]
Individual Space Heating[4)]	7.35	154.82	0.66
District Heating [4)]			
Air Conditioning (Cooling)			
Greenhouse Heating	14.93	192.42	0.41
Fish Farming			
Animal Farming			
Agricultural Drying[5)]			
Industrial Process Heat[6)]			
Snow Melting			
Bathing and Swimming[7)]			
Other Uses (specify)			
Subtotal	22.28	347.24	0.49
Geothermal Heat Pumps			
TOTAL			

[4)] Other than heat pumps
[5)] Includes drying or dehydration of grains, fruits and vegetables
[6)] Excludes agricultural drying and dehydration
[7)] Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2000 TO DECEMBER 31, 2004 (excluding heat pump wells)

[1] Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)		1			750
Production	>150° C					
	150-100° C					
	<100° C		1			400
Injection	(all)					
Total			3			1,500

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000	1	-	-	-	3	-
2001	1	-	-	-	3	-
2002	1	-	2	-	4	-
2003	1	-	2	-	4	-
2004	1	-	2	-	3	-
Total						

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2004) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1990-1994	2	0.2	0.15		20	80
1995-1999	0.15	0.1	0.05		70	30
2000-2004	0.40	-	-		-	100