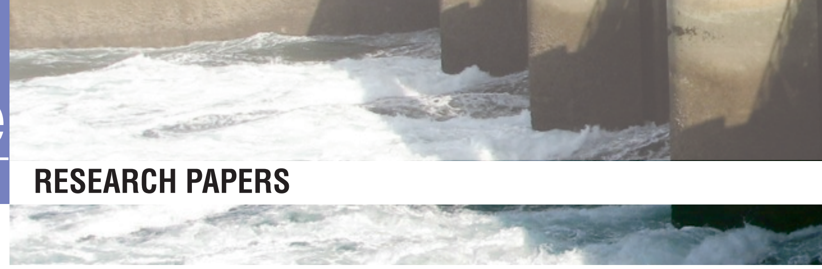

Energy consumption in the Italian mobile phones sector

The mobile phone market has experienced an exponential growth trend in the last ten years. Europe continues to be the main market in the developed countries, although in the last two years growth has witnessed a slow-down. Despite being already a mature market, Italy has a "penetration rate" (i.e., the number of active lines per 100 inhabitants) higher than 146, the highest in the European Union. Furthermore, in Italy about 70% of active lines use UMTS and HDSPA, the so-called 3G and 3,5G technologies, where G stands for Generation. It is important to point out that despite their higher power levels allowing faster data transmission and the use of increasingly complex services and software, these technological standards are high energy consuming. This scenario has suggested a study on the energy consumption of mobile phones and their associated equipment. The aim of the present article is to estimate the impact of this sector (including the so-called mobile network) on the Italian energy consumption

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Il consumo di energia elettrica nel settore della telefonia mobile in Italia

Il mercato della telefonia mobile ha mostrato un trend di crescita esponenziale negli ultimi 10 anni. L'Europa continua ad essere il principale mercato nell'ambito dei paesi "sviluppati", nonostante negli ultimi due anni abbia mostrato un rallentamento. L'Italia, pur con un mercato ormai maturo, presenta un "tasso di penetrazione", ovvero il numero di linee attive per 100 abitanti, pari ad oltre 146, il più alto nell'Unione Europea. Nel nostro paese inoltre circa il 70% delle linee attive è caratterizzato dall'uso di tecnologie UMTS e HSDPA, cosiddette di 3G e 3,5G (generazione). È importante sottolineare come questi standard tecnologici consentano sì una maggiore potenza, quindi trasmissioni sempre più veloci e l'utilizzo di servizi e software sempre più complessi, ma con un alto dispendio di energia. Questi dati hanno stimolato uno studio sul consumo di energia dei telefoni cellulari e degli strumenti ad essi collegati. L'obiettivo del presente lavoro è di stimare l'incidenza del settore (incluso il c.d. mobile network) sui consumi energetici nazionali

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Introduction

The Italian market of mobile communications has shown a clear growth trend for about a decade and, currently, the so-called penetration rate – that is the number of active lines per 100 inhabitants – is over 146, the highest in the European Union (EU) (European Commission, 2010). Following the authors' purpose to continue a discussion already started on this field and merged in two notes (Lagioia et al., 2006; Paiano et al., 2006), these considerations about the high use of mobile phones in our country have stimulated the study on energy consumption of these electronic devices and the instruments connected to them. The present article aims at estimating the incidence of this sector on the national energy consumption. The second section describes a brief quantitative and qualitative assessment of the mobile sector worldwide and in the European Union, besides in Italy. In the third one the methodological aspects of the study have been illustrated. In the sub-section the available data on the Italian mobile sector have been differentiated by transmission standard (GSM, UMTS, and HSDPA) per mobile phones, to identify three user profiles and the related usage patterns.

The discussion shows the results of the energy consumption analysis on the basis of the technical characteristics of chargers and batteries, whose transformation efficiency has been checked by carrying out some experimental tests.

Data on energy consumption of mobile devices have been added to mobile network's and BTS (Base Transceiver Station) localised in Italy. It comes, therefore, the estimate of energy consumption in the entire mobile phones sector. Final remarks show the incidence of this sector on the Italian energy system, besides the main issue related to a further growth trend in the mobile phones use.

The EU and the Italian mobile communications sectors

Quantitative assessment of mobile devices and active lines

In 2009 the mobile phones sold worldwide amounted to almost 1.2 billion, whereas the global active lines to about 5 billion. UMTS and HSDPA users were only about 13% of the total, but they generated 78% of the total traffic of voice and data services.

The market has continued to grow mainly driven by the newly industrialized countries which, especially considering the low penetration rate (China 56% and India about 45%), will be the most important markets in the short period.

Within the "developed" countries, however, the EU-27 has continued to be the biggest mobile market for as evidenced by the 122% expansion rate, higher than the United States (89%) and Japan (84%). Although now mature, in 2009 the Italian market showed a growing trend of the mobile sector and was not affected by the slowdown as in the rest of the European Union. The number of active lines in the EU rose from 390 million in 2004 to 650 million in 2009: a third of these came from people using 3G services.

In Italy the active lines[3] are currently about 89 million (63 million in 2004) and about 33.6 million users (approximately 65 million active lines) do use UMTS and HSDPA standards in prevalence over GSM[4]. The wider diffusion of the first two standards is due to the increasing use of innovative services such as mobile TV, mobile e-mail and instant messaging.

With regard to mobile broadband, which now represents a viable alternative in many countries, the average penetration rate is 19% in the EU, amounting to over 95 million users. Italy has an expansion rate of 16.5% and accounts for 10 million users. Of these, about 6 million connect by phone and just over 4 million (6.8%) by cards, modem and proper tools.

Quantitative assessment of mobile communications network

The data presented in the previous sub-section highlight the strong growth of the telecommunications sector, particularly for the mobile telephony. Another consequence of the strong growth is the increase in the number of installations and sites for radio frequencies in the territory. More than other segments of telecommunications, mobile phones witness a more widespread diffusion of radio systems based on territory, even in the answer for increasingly sophisticated services (Scharnhorst et al., 2005). The Base Transceiver Stations (BTS) are deployed throughout the territory as a function of population density, then with greater concentration in urban areas more densely populated. Their positioning varies from a few hundred meters to several kilometers of distance between them (e.g., in the case of rural areas) depending on the number of users served. The current BTS density on the Italian territory is 0.29 per km^2, much higher than radio-television, with a density of 0.13 per km^2. Conversely, the total power of BTS is much lower, amounting to 25% of the radio-television apparatus. At the end of 2009, in Italy there were just over 60,000 BTS, with a total capacity of about 242,000 kW (each plant has a capacity of approximately 4 kW) (ISPRA, Osservatorio CEM, 2011).

Materials and methods

Methodological aspects

In order to assess the overall power consumption of the mobile phone sector in Italy, mobile phone users were grouped into three categories, based on the intensity of use (*low*, *medium*, and *high*) of their mobile phones. The corresponding transmission 2G, 3G and 3,5G (GSM, UMTS and HSDPA) technologies were also identified (Ayres, Williams, 2004; Birchler et. al., 2003). Among the large variety of mobile phone models currently available on the market (where each phone model is characterized by virtually unique technical specifications), three "representative" models were chosen: one model for each of the aforementioned categories. The "reference" models had been manufactured by leading companies. For each model, all the technical characteristics necessary to estimate energy consumption were considered (e.g., power consumption, energy consumption, etc.) (Schaefer et al., 2003). Additionally, for each category of users, a model describing the use of the mobile phone as a function of the services used in a month period (e.g., voice calls, text messages, data exchange) was identified. Combining these data with the information regarding different types of mobile phones (and, hence, the different categories of users), it was possible to evaluate the energy consumption associated to each category of users for 2009.

In the evaluation of the electrical energy consumption of the considered devices, both the efficiency of the battery-charge process and the efficiency of the battery usage were appropriately taken into account. In this regard, to assess both parameters, experimental tests were performed on two mobile phones: one GSM, and the other UMTS.

The total energy consumption was then estimated by considering the total number of users of each category (nationwide). Finally, by also considering the energy consumption of the network infrastructure and of radio mobile antennas, it was possible to estimate the total energy consumption of this sector and its incidence on the total energy consumption in Italy.

Analysis of the data

The digital mobile telephone technologies were grouped into macro-categories GSM/GPRS, UMTS/WDCMA, and HSDPA (table 1): these technologies differ in operating frequency band and bit-rate. *Tab 1* summarizes the main technical characteristics (i.e., those necessary to evaluate energy consumption) of the mobile phone models that were chosen as "reference". As expected, it appears that the more advanced the technology, the more power it requires.

The three categories of users (*low, medium* and *high*) substantially correspond to the three transmission technologies of table 1 (i.e., GSM, UMTS and HSDPA, respectively), since only some of them can support advanced services and applications. The percentage incidence of each category of users on the total num-

Transmission technology	Mobile phone model	Battery			Voice calls		Standby mode	
		Voltage (V)	Capacity (mAh)	Energy (Wh)	Time (h)	Power (W)	Time (h)	Power (W)
GSM	Nokia 3230	3.7	760	2.812	2.5	1.1248	240	0.011716
UMTS	Samsung U-700	3.7	900	3.33	5	0.666	300	0.011
HSDPA	Nokia N 95	3.7	950	3.51	2.7	1.3	192	0.01828

TABLE 1 *Power and energy consumption per mobile phones category*

Source: estimates made by the authors, based on companies data

User categories	Percentage incidence	Number of active telephone lines	Voice calls	Text messages*	Internet connection	Standby mode	Off mode
	%	millions	hours/month/user				
Low	26.1	23.2	1.45	0.05415	0	418.496	300
Medium	67.4	60	6	0.139	0.8	473.06	240
High	6.5	5.8	10	0.4865	18.33	691.184	0

* The number of text messages (per month, per user) was assumed to be equal to 15, 100, and 350 for *low*, *medium* and *high* categories of users, respectively.

TABLE 2 *User profiles and usage patterns*
Source: estimates made by the authors

ber of mobile phone users (in Italy) was also evaluated. Additionally, by considering *i)* the total hours per month spent using the mobile phone (i.e., making voice calls, sending text messages, internet connection), and *ii)* the total hours in which the phone is either off or in the standby mode, it was possible to derive a model that suitably describes the patterns regarding the usage of mobile phones and of the related services (table 2).
On the basis of the available data and the users characteristics , the three user profiles show the following characteristics. The first user profile is characterized by a low daily usage of the mobile phone (and, consequently, low monthly usage), corresponding to approximately: 1.45 hours of voice calls, 15 text messages, 300 hours in the power-off mode (i.e., 10 hours a day), and, as a result, 420 hours in the standby mode. The *medium* user profile includes: 6 hours of voice calls, 100 text messages, 0.8 hours of internet connection, 240 hours in the power off mode (i.e., 8 hours a day) and 480 hours in the standby mode (these figures are referred to a month). Finally, for the *high* user profile, which employs the HSDPA technology and makes an extensive use of the internet, the following data were deduced: 18 hours of data exchange[5], 10 hours of voice calls, 350 text messages, almost 700 hours in the standby mode and 0 hours in the power-off mode (EIAA, 2011; AGCOM, 2011).

Energy consumption and conversions
The second phase of this study was dedicated to the assessment of the energy consumption associated to the different "modalities of use" of mobile phones, so as to convert mobile phones' "functioning hours" into "consumed energy".
Table 3 highlights the amount of power and the time required for sending a text message. In particular, the "reference" text message was considered to be 300 byte, sent either via GSM or UMTS technologies, in 13 s (0.00361 h) or 5 s (0.00139 h), respectively. In the literature (Perrucci et al., 2009), it is reported that although the time required for sending a text message via GSM technology is longer than the time required for sending the same message via UMTS technology, the energy consumption in the latter case is definitely higher than in the first case.
As for the internet connection, it is important to emphasize that the energy consumption of UMTS connections is remarkably lower than GPRS technology (which is associated to the GSM network). For the estimates reported herein, it was assumed an energy consumption of 35.12 J, that is 0.00976 Wh/MB (million of bytes) for transmission via the UMTS technology, and of 0.027795 Wh/MB for transmission via the GSM technology (Perrucci et al., 2009).
Bytes were converted into hours (and vice versa) by using equation no. 1. This equation also takes into ac-

Transmission technology	Power (mW)	Time (h)
GSM	240	0.00361
UMTS	880	0.00139

TABLE 3 *Power and time required for sending one text message*
Source: estimates made by the authors, based on the data available in the literature (Perrucci et al., 2009)

count the bit-rate, which is assumed to be 384 kbps (thousands of bits/s) for UMTS connections and 1 MB/s for HSDPA connections (table 4): in fact, these values represent the bit-rate that appears to be the "actually achievable" during connections. Finally, it is worth mentioning that for expressing multiples in Informatics-related quantities, the base-two approximations were used; whereas, for Telecommunications-related quantities, standard multiples were used.

Data transfer time (s) = Data quantity (MB) x 8/bit-rate (bps) [Eq. no. 1]

Finally, for *medium* and *high* profiles, the amount of hours dedicated to the internet connection was calculated, so as to evaluate the total amount of hours/month for each user, then convert hours into MB, and eventually assess the corresponding energy consumption (*tab. 4*).

Energy efficiency

User categories	Bit rate (kbps)	Time (h)	Bytes (MB)
Medium	384	0.8	125.28
High	1,000	18.33	8,248.5

TABLE 4 *Conversion from hour to Byte*
Source: estimates made by the authors

The analysis conducted in this work is based on average values of the energy efficiency of the battery and of the battery charger. These two parameters were assessed through experimental tests performed on two mobile phones: one GSM (manufactured by Sagem) and the other UMTS (manufactured by Samsung). The tested phones were not brand new; on the contrary, they had already been used to different extents. In this regard, it is important to underline that the lifetime of a battery is limited and that its efficiency decreases with charge cycles and with age. The UMTS and, even more so, the HSDPA technologies provide more power, thus allowing faster bit rate and the use of complex services and software; nevertheless, this translates into higher energy consumption. Additionally, high power may lead to battery overheating (with temperatures as high as 45 °C), which, in turn, results in an additional loss. All the aforementioned aspects have also great influence on the battery wear: in fact, considering the limited battery life, mobile phone users must recharge the battery very often, thus accelerating charge cycles and ultimately compromising the service life of the battery and its efficiency.

With regards to the battery efficiency, in this study, it was considered an average value of approximately 50% of the nominal value for *low* and *medium* users, and of 65% of the nominal value for *high* users –in fact, users of this category are expected to change their mobile phones more frequently; therefore, batteries can be considered "newer".

The data on the reduction of the energy efficiency of the battery were validated through experimental tests, which, in one specific case, showed a reduction higher than 50%.

It is also important to point out that the nominal capacity of a battery indicates the maximum charge that can be stored by the battery.

With regard to the mobile phone charger, the efficiency is different for the different chargers, the same applies to the input and/or output voltage and/or current specifications, for which the values indicated on the tag are only nominal. For these reasons, the assessment of the actual energy consumption involves accurate calculations which should also take into account all the energy losses that might occur when electricity is transmitted from the AC wall outlet up to the device.

All these parameters influence also the battery life of the mobile phone. It is worth pointing out that for leading brands (such as Nokia, Samsung, etc.) the difference between nominal values and actual values, e.g., for the output of a mobile phone charger is in the order of 20-30%; whereas, for less-known brands, this difference can be as high as 50-60 %, as also demonstrated through experimental tests.

Finally, another important parameter is the energy efficiency of the mobile phone charger, which is the amount of output energy (from the charger) that can be stored in the battery. This parameter can be evaluated through equation no.2[6], where Ln indicates the natural logarithm and Pno is the nominal output power (as reported directly on the charger) expressed in Watt:

$$Eff_{min} \geq 0.075 \text{ X Ln (Pno)} + 0.561 \quad \text{[Eq. no. 2]}$$

The results of the experimental tests show the wear of the battery and how the "actual" efficiency of the charger influences energy consumption.
In this work, to evaluate energy consumption from the electrical power supply during the battery charge , for all the categories of mobile phones, it was assumed a duration of the charge cycle of 2.5 hours. It is worth mentioning that, in this way, it was accounted only for the actual time of an average charge cycle (*active mode*), and not for the time, often long (the so-called *idle mode*), during which the battery has already been fully charged, and the telephone is still connected to the charger which absorbs energy from the electrical power supply (although only a small amount of energy).
Based on the experimental results, it can be deduced that a 2.5-hour battery charge absorbs slightly less than 7 Wh.

Results and discussion

Mobile phones electricity consumption

Based on data reported in Tables 1-4 the power consumption for mobile phones in Italy can be calculated, first reported to user/month (table 5). The data show how the monthly energy consumption per user appears to be much higher for the *high* category, mainly because of the intense connection to the Internet.
These data allow then to calculate the number of charges made within a month by type of device and/or usage pattern.
In the case of the *medium* user, for example, it takes over 10.5 Wh of electricity per month, whereas the battery efficiency of the related device (Samsung U-700) is about 50%, and then about 1.6 Wh (as occurred in one of two experimental trials and on data in table 1) of the energy that can be contained in the battery. So it is possible to estimate that it takes about 7 charges per month, i.e., 84 per year.
To calculate energy consumption by using the charger at the electrical power supply, keeping in mind that a charge cycle absorbs less than 7 Wh it can be estimated an annual consumption of around 588 Wh for the mobile reference *medium* category. The same calculation can be done for other types of users and the results are shown in table 6.
The annual consumption data obtained for each user can then be multiplied by the active lines available in Italy in 2009, grouped into the three reference categories . It emerges that about 68 GWh of electricity, for about 89 million active lines, have been consumed in the reference year (table 7). For the total value of the entire mobile phone sector it is necessary to add the BTS energy consumption on the Italian territory identified in the following sub-section.

Energy consumption of Base Transceiver Stations

The energy consumption of a BTS is due to the functioning of equipment and to the air-conditioning of the building, useful to the proper working of the transmission apparatus. The energy consumption can be shared between these two main factors according to the considered study (Ispra, University of Naples, 2009). In particular, it is possible to ascribe 2/3 of the energy used to the transmission facilities and 1/3 to conditioning equipment. It should be noted that energy consumption is higher for BTS with GSM technology (about 111 kWh/day and 40,085 kWh/year) than those with UMTS ones (73 kWh/day and 26,268 kWh/year). Considering an average daily consumption of about 97 kWh per plant, the annual consumption will be 35,405 kWh, which, multiplied by the number of plants on the national territory, gives about 2,124 GWh consumed in Italy per year.

User categories	Voice calls	SMS	Internet	Stand-by	Total
Low	1.63096	0.01299	0	4.90310	6.54706
Medium	3.996	0.12232	1.2227	5.20366	10.54468
High	13	0.42812	80.5	12.6348	106.56292

TABLE 5 *Electricity consumption per mobile phone user (Wh/month/user)*
Source: estimates made by the authors

User categories	Charge/year	Wh
Low	60	420
Medium	84	588
High	564	3,948

TABLE 6 *Electricity consumption per mobile phone user (Wh/year/user)*
Source: estimates made by the authors

User categories	Number of active lines (million)	GWh
Low	23.2	9.744
Medium	60	35.280
High	5.8	22.8984
TOTALE	89	67.922,4

TABLE 7 *Total electricity consumption for the mobile phones use in Italy in 2009*
Source: estimates made by the authors

Final remarks

The total annual consumption of electricity of the total mobile phone sector is estimated to be about 2,200 GWh, and the energy consumption resulting from the direct use of the devices accounts for only a small percentage (about 3%), remaining the electricity consumption of the network, that is BTS, the most important part.
It should be noted that, concerning the use of the devices by macro-categories of identified users, the author's analysis has simplified the patterns of usage to estimate the total energy consumption.
The estimated figure is certainly lower than the real one for many reasons:
1) power consumption of mobile phones is not the same according to the application used (calls, Internet connection, etc). It changes because of several factors, the most important being the user's status, stationary or moving. The latter condition requires intensive use of energy to run any type of services;
2) the use of the phone is clearly widespread during daylight hours and usually very intensive at time band of peak telephone traffic, so that the energy required can be much more significant;
3) the charging modes by the appropriate charger are very variable and certainly incorrect in most cases (incomplete charge, with mobile phones switched on) or otherwise charging the phone for a long time (*idle* mode), for instance during the night or even leaving the charger plugged into the grid even if the phone is unplugged (the so-called *no-load)* (Ostentdorp et al, 2004). These practices tend to reduce the efficiency of the batteries more rapidly;
4) information on real use of device from users is insufficient and fragmentary. This is still more true when it comes to energy consumption data that appear to be few and not so "standardized" probably due to the variety of devices on the market and the use of transmission technologies.
From the results of this study other considerations emerge. In the year of reference, 2009, the consumption of electricity in Italy totalled 300,000 GWh roughly, and then the entire mobile phone system is equal to 0.7% of national electricity consumption. It should be noted that, as already mentioned, the figure is underestimated. It emerges how the use of electronic communications, particularly mobile phones, can be conflicting with the apparent dematerialization often ascribed to this field.

Considering that a massive growth in the use of the latest generation of mobile phones (3.5G and the next ones) is forecasted, as it has been pointed out, more and more energy for their functioning will be required. Therefore it becomes important to keep up research and further experimental tests to clarify what is the real power consumption. Moreover the relevance of the enhancement concerning the means of communication should be stressed with the aim to spread awareness among users that the most efficient consumption patterns help saving energy and resources.

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Note

This work is the result of the authors' commitment. Particularly, the sections The EU and the Italian mobile communications sectors, Materials and Methods, Results and discussion and the reference collection are ascribed to *Paiano*; Introduction, Results and discussion and Final remarks to *Lagioia*, Experimental Tests and sub-section Energy Efficiency to *Cataldo.*

1 In Italy it continues to be significant the number of users who have a dual SIM card, hence the numerical difference between users and active lines.
2 The acronyms GSM, UMTS , and HSDPA stands for Groupe Special Mobile, Universal Mobile Telecommunications System, and High Speed Downlink Packet Access, respectively.
3 With regards to the hours of internet connection, it is worth mentioning that *i)* for the *medium* user profile, 90,000 Mbytes of exchanged data (equal to approximately 0.8 hours) were considered: this figure represents the amount of data exchanged in 2009; *ii)* for the *high* user profile, the time dedicated by users to broadband internet connection was considered, equal to 31.6 hours/month (EIAA, 2011), appropriately reduced to 58.6% (equal to 18.33 hours/month), which is also the percentage incidence of mobile phone-based broadband internet connection on the total number of users (approximately 10 million people) who use broadband internet connection; the remainder use other devices such as USB modems.
4 The equation was extrapolated from the criteria elaborated by EPA, under the Energy Star programme, for measuring the minimum efficiency of low-power (from>1 to ≤ 49 W) chargers (AC-AC, AC-DC), on active mode (EPA, 2011).