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DC4Cities
An environmentally sustainable data centre for Smart Cities

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First market analysis
D2.2

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EXECUTIVE SUMMARY

DC4Cities follows a vision: Data centres supporting a Smart City in its goal to use a high percentage of renewable energy sources in the city’s energy source mix. Even though, a set of conditions (e.g. smart meter market penetration and reformation of the EU emissions trading system) that all together will increase the potential for a striving market for DC4Cities is emerging, the current and near future situation might not allow to leverage on the full potential of the DC4Cities approach. Therefore, in the first iteration of the market analysis, the focus is on the identification of the ideal context for DC4Cities and the outline of a market for DC4Cities if this potential were unleashed within the next decades.

In order to show where and how DC4Cities could be marketed today or in the very near future, the status quo of a market for DC4Cities is first analysed from a data centre, an energy system as well as from a smart city point of view. This is taken as a basis for the characterisation of a potential future environment for DC4Cities and the identification of characteristics of data centres that are part of this environment. These findings conclude in a careful estimation where and to which extent a DC4Cities based product portfolio could be successfully introduced into the market today and in the future.
### CONTRIBUTORS TABLE

<table>
<thead>
<tr>
<th>Document Section</th>
<th>Author’s Name(s)</th>
<th>Reviewer</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Introduction</td>
<td>SONJA KLINIGERT</td>
<td>THOMAS SCHULZE</td>
</tr>
<tr>
<td>II.1 The Energy</td>
<td>SILVIA SANJOAQUIN VIVES, MILA REY PORTO</td>
<td>ROBERTO CHIAPPINI</td>
</tr>
<tr>
<td>Framework in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II.2 The Data Centre</td>
<td>SONJA KLINIGERT, GORKA ROLDAN, FREDERIC WAUTERS, JORDI GUIJARRO</td>
<td>FREDERICO LOMBART BADAL, TORBEN MÖLLER</td>
</tr>
<tr>
<td>Framework in Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II.3 Smart Cities</td>
<td>FEDERICO LOMBART BADAL, FRANCESC CASAUS BARREDA, ALBERT FITER, SONJA KLINIGERT</td>
<td>MARIA PEREZ ORTEGA</td>
</tr>
<tr>
<td>in Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III.1 The Energy Market</td>
<td>SILVIA SANJOAQUIN VIVES, MILA REY PORTO, FREDERICO LOMBART BADAL, FRANCESC CASAUS BARREDA, SONJA KLINIGERT</td>
<td>TERESA VIA, SONJA KLINIGERT</td>
</tr>
<tr>
<td>in Smart Cities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III.2 Ideal DC4Cities</td>
<td>SONJA KLINIGERT, FREDERIC WAUTERS, MARCUS KESSEL, ANDREA QUINTILLIANI</td>
<td>FLORIAN NIEDERMEIER, THOMAS SCHULZE, TORBEN MÖLLER, NICOLAS GUEUNING</td>
</tr>
<tr>
<td>Data Centres</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV. Final Conclusions</td>
<td>SONJA KLINIGERT</td>
<td>ANDREAS BERL</td>
</tr>
<tr>
<td>about the DC4Cities Market</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V. Outlook</td>
<td>THOMAS SCHULZE</td>
<td>TORBEN MÖLLER</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

I. Introduction ........................................................................................................... 7

II. Starting Conditions in Europe .............................................................................. 8
   II.1. Energy Framework in Europe ...................................................................... 8
       II.1.1. Relevant Energy Legislation ......................................................... 8
       II.1.2. Current Infrastructure ................................................................... 16
   II.2. Data Centre Framework in Europe .............................................................. 18
       II.2.1. Relevant Data Centre Legislation ................................................. 18
       II.2.2. General Market Structure ............................................................ 19
       II.2.3. Environmental Impact of Data Centres ....................................... 23
       II.2.4. Suitable Data Centres .................................................................. 27
   II.3. Smart Cities in Europe ............................................................................... 30
       II.3.1. Smart Cities Roadmap .................................................................. 30
       II.3.2. Smart Cities Infrastructure ............................................................ 34
       II.3.3. Smart Cities Suitable for DC4Cities ............................................ 36

III. Ideal Context for DC4Cities Potential ................................................................. 41
   III.1. Energy Market in Smart Cities ................................................................. 41
       III.1.1. Market Actors ............................................................................. 41
       III.1.2. Market Structure for Dynamic Pricing ...................................... 48
       III.1.3. Technology as a Business Enabler ............................................. 50
       III.1.4. The ideal Smart City Policies ..................................................... 58
   III.2. Data Centre View .................................................................................... 60
       III.2.1. Business Models and SLAs ......................................................... 60
       III.2.2 Legal ownership .......................................................................... 63
       III.2.2. Service Characteristics and Workload Shape ............................. 64
       III.2.3. Customers/Users ...................................................................... 66
       III.2.4. Energy supply of DCs ................................................................. 69
       III.2.5. Technical Enablers ..................................................................... 71

IV. Final Conclusions about the DC4Cities market .................................................. 73
   IV.1. Today’s DC4Cities Market ...................................................................... 73
   IV.2. The Potential Market for DC4Cities in the 2030s .................................... 76

V. Outlook ............................................................................................................... 80

VI. References ....................................................................................................... 81
Table of Figures

Figure 1 – Projections Europe 2020 Strategy [ECC12] .......................................................... 9
Figure 2 – Share of energy from renewable sources, EU28, [ENR14] ............................ 10
Figure 3 – National shares of fuels in gross inland energy consumption, 2012 [NCS12] ....... 10
Figure 4 – Estimated Share of renewable energy in gross final energy consumption, 2012, [ENR14] .............................................................................................................. 11
Figure 5 – GDP and Gross Inland Consumption European Commission, [TRE13] ............. 12
Figure 6 – RES percentage in electricity generation, [TRE13] ........................................ 13
Figure 7 – Current infrastructure [SSG01] ........................................................................ 17
Figure 8 – Forecast Public Cloud Services [FCS01] .......................................................... 20
Figure 9 Data Center Map overview [DCM01] ................................................................. 21
Figure 10 - Growth Rates of Public Cloud Services Market [GGC01] ............................... 22
Figure 11 - Data Growth Rate .......................................................................................... 23
Figure 12 - Clouds Growth: A Breakdown [STR12] ......................................................... 24
Figure 13 - Cloud Electricity Demand [CED14] ............................................................... 25
Figure 14 - CO2 emissions by Fuel Source for Electricity Generation [RER13] ............. 26
Figure 15 - Estimated CO2 emissions [SRT11] ............................................................... 26
Figure 16 - Global Data Centre Emissions [SMT12] ......................................................... 27
Figure 17 - Suitability of Business Models ..................................................................... 28
Figure 18 – SLA Flexibility .............................................................................................. 29
Figure 19 - The six smart dimensions ............................................................................. 31
Figure 20 - Energy 2020 targets ...................................................................................... 32
Figure 21 - Europe 2020 strategy [EIS20] ...................................................................... 33
Figure 22 - European initiative on the Smart Cities technology roadmap [ECS09] .......... 34
Figure 23 - Gartner forecasts for the mass adoption of key technologies for the Smart City [GAR11] ...................................................................................................................... 36
Figure 24 - Smart Cities according to at least one of the six EU smart City Characteristics. Total > 240, because some qualified in more than one characteristic .................... 37
Figure 25 – Bi-directional flow of information demand aggregator .................................. 42
Figure 26 – Peak-shaving through demand response ...................................................... 44
Figure 27 – EMA-SC role as Aggregator ........................................................................ 45
Figure 28 – Energy performance Contract Scheme [MRE01] .......................................... 46
Figure 29 – ESCo project model [MRE01] ..................................................................... 47
Figure 30 – Possible example of cost structure throughout a day in the Spanish grid ....... 48
Figure 31 – Energy daily wholesale market prices throughout a day in the Iberian market [OMI01] ...................................................................................................................... 49
Figure 32 – Smart Grid [SMG01] .................................................................................... 50
Figure 33 – Storage in the electricity grid ...................................................................... 52
Figure 34 – Storage technology state of the art and storage capacity [FRA11] ............... 53
Figure 35 – Smart metering benefits
Figure 36 – EMS information flow
Figure 37 – EMS continuous improvement cycle
Figure 38 - Schema about the interrelations among the city services [ICS01]
Figure 39 - Example of a wireless sensor network under smart grid environment
Figure 40 - Schema Smart City Infrastructure [SSC01]
Figure 41 - IT systems evolution through the Smart City infrastructure [ISE01]
Figure 42 - SLA Flexibility
Figure 43 – Forecast Hosting and Cloud Market
Figure 44 – Data Center Energys Metrics [DCE01]
Figure 45 - ICT-Smart City cross-fertilization
Figure 46 - Mixed-use DC load shape
Figure 47 - Relationship between IT Services, Customers and Consumers
Figure 48 - Ideal Flexibility Provided by IT Customers and IT Consumers to DC4Cities
Figure 49 – Growth Rate Of Public Cloud Services
Figure 50 – Growth Rate of Public Cloud Services In Multi-Owner DCs
Figure 51 - Data Centre Markets in Parts of Central Europe [DCM]
Figure 52 - Representation Of Byteunits [ROB01]
Figure 53 - Assumptions for input prices of oil, coal and gas until 2050 [APO13]
I. INTRODUCTION

DC4Cities is a visionary approach: a data centre ("DC" or a federation of data centres "DCF") inside a real smart city that aims at a high share of renewable energy at its energy mix is not a very realistic setting under the current circumstances. Even though some smart cities have issued for themselves the goal of increasing their share of renewable energy sources, the economic framework (both from the European as from the national part) today is not very supportive for a DC4Cities system. For instance, nowadays, energy tariffs reward the consumption of fossil or nuclear energy sources because “green” tariffs are more expensive than “regular” tariffs – one reason being that CO2 can be emitted nearly for free and the risk of depositing radioactive material is financed by the whole society.

The target market segment for DC4Cities are DCs situated within the boundaries and/or legislation of a Smart City (defined according to D2.1) that aims at a high percentage of renewable energy sources in the city’s energy source mix and via some way or other tries to integrate local DCs into its energy goals. To our understanding this context is realized nowhere in the world, and only a handful of smart cities are clearly on this track (see section II.3. ).

This means that the current market size for DC4Cities is rather small. However, there are a set of emerging conditions that all together will increase the potential for a striving market for DC4Cities in the coming decades1 (see also section II.1.1. II.3.1. ):

- The EU smart city roadmap
- The EU objectives to increase of the share of renewable energy sources to 27% until 2030
- Reforming the EU emissions trading system
- The EU objectives for energy efficiency (+30% until 2030)
- Smart meter market penetration
- Increasing awareness of climate change

However, in order to create a context where a data centre in a smart city has the goal to use substantially more than 50% of intermittent energy sources for the data centre operation, this may not be enough.

Therefore, in the first iteration of the market analysis of DC4Cities, the focus will lie on the identification of the ideal context for DC4Cities and the outline of a market for DC4Cities if this potential were unleashed within the next decades. This endeavour leads to the following structure:

The first chapter will analyse the status quo of a market for DC4Cities in order to show where and how DC4Cities could be marketed today or in the very near future (Chapter II). This will be done from the point of view of the energy system (section II.1. ), a data centre in a smart city of today (section II.2. ) and it will look at today’s smart city landscape (section II.3. ).

The main part of the document will be dedicated to a potential future environment for DC4Cities (section III.1. ) and to the characteristics of data centres that are part of this environment (section III.2. ).

These findings will culminate in a careful estimate where and to which extent a DC4Cities based product portfolio could be successfully introduced into the market today and when the smart city environment has matured (chapter IV). Finally an outlook will summarize the findings and project the next steps within the WP2 market analysis tasks.

1 http://ec.europa.eu/clima/policies/package/index_en.htm
II. STARTING CONDITIONS IN EUROPE

II.1. Energy Framework in Europe

II.1.1. Relevant Energy Legislation

In order to reduce the European dependency of fossil fuel imports and contribute to slow down climate change, the set of targets known as “20-20-20” has been created\(^2\). These three targets establish the guidelines for whole of the European energy policy. The aim of the Europe 2020 strategy is triple: environmental, geostrategic and economic.

By 2020, greenhouse effect gases (mainly CO\(_2\)) emissions are required to decrease by 20% from 1990 levels, aiming to reduce the EU’s contribution to climate change. Also, a target share of 20% has been established for the percentage of renewable primary energy consumed in the EU, reducing the need for energy imports and therefore lowering the EU’s energy dependence from third countries. Furthermore, the 2020 strategy aims to improve energy efficiency in the EU by 20% comparing to 2020 previsions\(^3\).

These targets set the basis for all further European energy policy. European Directives inspired by the 2020 strategy provide the legal framework necessary for Member States to develop their specific legislation, which must be aimed in the same direction and cannot be laxer than the European Directives in their objectives and procedures.

A selection of the most relevant energy challenges/legislation that has an impact on the current and future market size of DC4Cities is summarized in this section.

- Renewable energy Directive: DC4Cities system is designed with the aim of maximizing the usage of renewable energies. Directive 2009/28/EC, on the promotion of the use of energy from renewable sources, establishes a common framework at EU level for the promotion of energy from renewable sources, setting mandatory national targets in gross final consumption of energy.

- Energy Efficiency Directive: DC4Cities moreover promotes the energy efficiency in Data Centres. Directive 2012/27/UE, on energy efficiency, establishes a common framework of measures for the promotion of energy efficiency within the EU in order to ensure the achievement of the EU 2020 20% objective on energy efficiency.

- Single European Electricity market: DC4Cities system will maximize the usage of renewable energy by implementing flexibility mechanisms to shift consumptions. European Directives 2009/72/CE and 2009/73/CE concerning common rules for the international markets in natural gas and electricity respectively, establish a common framework for trans-border trading. They are aimed at increasing market integration in the EU. This will determine the electricity market structure and prices, which is one of the key enablers to implement demand response mechanisms.

DC4Cities Project will contribute to the objectives of Europe 2020 Strategy. It will contribute directly to the RES objective by adaption to RES availability, thus enabling higher penetration of intermittent energy sources. As a consequence, DC4Cities also aims at reducing GHG emissions. Furthermore, the adoption of DC4Cities will make Data Centres’ consumption more manageable by reducing the number of active hardware units when they are not needed. This contributes to increase energy efficiency.

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\(^2\) Established by the 2020 climate and energy package
\(^3\) http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/introduction
Recent reports show the EU is still not on track regarding the increase in energy efficiency. It is worth noting that Directive 2012/27/EU on energy efficiency and consequent action plans have not yet come to full effect and therefore further projections might show a more favorable scenario. In any case, it is expected that the other two goals will be achieved without further major policy changes.

![Graph showing projections for Europe 2020 Strategy](image)

**Figure 1 – Projections Europe 2020 Strategy [ECC12]**

**II.1.1.a. Directive 2009/28/EC on the promotion of the use of energy from renewable sources**

The goal of this Directive is to establish a common framework to foster the use of renewable energy sources. To each Member State has been assigned an individual target regarding the fraction of gross final energy consumed that must come from renewable sources. National targets will guarantee that the overall goal of 20% gross final energy from RES established by the Europe 2020 strategy is achieved with a fair distribution of the efforts. The increase in energy from RES is expected to be gradual but in accelerating trend.

Set targets are not sector-specific, except for the transport sector: 10% of energy used for transport must come from RES, including electric vehicles and plug-in hybrids.

Member States must submit national plans, detailing the measures to be taken, and quantifying their impact regarding the fraction of energy from RES. Actions include support mechanisms that encourage the use of RES, obligations, and cooperation mechanisms between Member States and/or third countries. Action plans will be evaluated and approved by the European Commission.

Concerning the electric system, Member States will ensure electricity from RES enjoys priority or guaranteed access to the electricity market in order to avoid the loss of clean energy from RES. Furthermore, generating agents that generate electricity from RES will be guaranteed the right to connect to the electric grid. Member States are entitled to force transmission and distribution systems operators to totally or partially assume the costs of connecting renewable generation facilities to the grid, within a reasonable period of time.

Tariffs for transport and distribution must not represent any form of discrimination towards electricity generated from RES, especially and in particular when the generating facility is located in an isolated or unpopulated area.

**II.1.1.b. Renewable energies context and previsions**

Throughout the last decade, the share of gross final energy consumption from renewable sources has risen steadily from over 8% in 2004 to 14% in 2012.
The following chart shows share of Gross Inland Consumption in each country for the year 2012. As the charts below show, high differences between Member States exist.

The highest shares can be found in northern countries like Sweden, Finland or Latvia, having shares higher than 30%. However, the average value in almost all Member States is much lower, approximately 10% - 15%. Isolated countries, like the islands of Malta and Cyprus, have the lowest shares of renewable, under 5% [ETR01].
The following chart shows the percentage of gross final energy demand for each country in the EU-28, compared to their individual target for 2020. There is a great difference in the current degree of consecution of the 2020 target between the different countries. While some countries, like Estonia or Sweden, have almost reached or even surpassed their target, others will probably fail in achieving their national goal [ETR01].

The chart below shows the share of energy from RES in gross final consumption. It is worth noting that energy usage has been measured using different criteria to the chart above, and therefore there are differences in the share of renewable energy charted for each country.

Gross inland consumption includes all energy usage, including fuel usage for non-energetic purposes, while gross final energy consumption accounts for final energy usage in its final form (electricity and heat). Also, electricity imports (Electrical Energy in the chart above) may come from a renewable source, but as electricity is not an energy source in itself it is charted separately.

An overview of the usage of renewable energies at EU level in the horizon 2030 can be obtained from [TRE13]. This document provides a detailed forecast on mid-to-long-term demography, economics and energy. This latest version takes into account the effects of the economic crisis that started in 2008, leading to structural changes in the economy and its relation to energy usage. It was completed in December 2013. Moreover, this publication takes into account the encouragement energy efficiency and renewable generation in order to pursue the goals established by strategy Europe 2020 through the European and national legislations that have been developed since 2009.

Therefore, the economic crisis and latest changes in European policies made the 2013 update necessary to better predict the evolution of energy trends in comparison to previous publications.

Said document provides forecasts up to the year 2050. It is worth noting that these predictions are based on how the economy is expected to evolve, and long-term predictions
can change substantially depending on political measures or changes in the economy such as further economic recessions. Mid-term forecasts are more important for DC4Cities than long-term predictions. Therefore, in the context of the project, it is only worth analysing forecasts up to 2030.

It is important to remark the main features of the economic context that has been assumed for the development of this study. After the economic recovery, European GDP is expected to grow at a steady pace, while population grows slowly, partly because of a dynamic immigration trend. GDP per capita growth prospects anticipate growth at an average rate of 1.7% p.a. until the 2030 horizon.

Fossil fuel prices have swiftly grown to reach pre-crisis levels, and are expected to keep rising steadily until the report’s horizon. High fossil fuel prices make alternative sources of energy, e.g.: RES, more attractive by comparison, while increasing potential economic savings through increased energy efficiency in generation and end-use.

Despite GDP growth, previsions state that energy consumption will decrease to 2030 due to efficiency measures. The following chart shows the 5-year mobile average GDP and Gross Inland Consumption (GIC):

![Figure 5 – GDP and Gross Inland Consumption European Commission, [TRE13]](image)

The weight of electricity in final energy consumption is expected to grow significantly over the next few decades; therefore the percentage of electricity generated from RES will have a growing impact on the fraction of total energy consumption from renewable sources.

Previsions regarding electricity generation forecast a 35% share of electricity generated from RES in 2020, and 44% in 2030. The bulk of the increase in electricity generation from RES will correspond to a massive deployment of wind technology. However, other RES will also become more widespread. For instance, biomass is expected to grow steadily during the demonstrated period [TRE13].

Electricity generation from RES is expected to grow strongly over the next years, from 553 TWh in 2010 to 1,387 TWh in 2030. As has been mentioned before, wind technology deployment will account for the bulk of RES generation growth, as electricity generation from wind energy will grow from 149 TWh in 2010 to 768 TWh in 2030.
Within this context of growing percentages of electricity generation from RES, a large fraction of which is expected to come from intermittent sources such as solar or wind energy. The ability to become energy adaptive (demand response mechanisms, energy storage, etc) will become a key factor to allow intermittent RES penetration [TRE13].

II.1.1.c. Directive 2012/27/EU on energy efficiency

The aim of this Directive [EED12] is to establish a common framework for energy efficiency measures in order to enforce the achievement of a 20% increase in energy efficiency in the UE, while also laying foundations for further measures that improve energy efficiency. It intends to accomplish its goals by solving shortcomings and eliminating obstacles in the energy market that can block the improvement in energy efficiency.

This Directive requires each Member State to establish a national energy efficiency indicative target, which may vary depending on parameters such as baseline efficiency or GDP evolution. This target must be set for one of the following variables: primary/final energy consumption, primary/final energy savings or energetic intensity and shall take into account that the EU 2020 energy consumption has to be no more than 1,474 Mtoe of primary energy or no more than 1,078 Mtoe of final energy. With the accession of Croatia the target was revised to 1,483 Mtoe primary energy or no more than 1,086 Mtoe of final energy.

Every State is required to present an Energy Efficiency plan, quantifying the impact of annual energy savings by sector and measure, which must be approved by the Commission. Energy savings over the obligation period (01 January 2014 – 31 December 2020) can be obtained by using energy efficiency obligations schemes or other targeted policy measures to drive energy efficiency improvements in households, industries and transport sectors.

This report summarizes the Energy Efficiency Directive, focusing on the aspects that have been identified as relevant regarding data centres and DC4Cities:

- **Obligations for Public Bodies**

  Article 5 of the Energy Efficiency Directive imposes an exemplary role of public bodies’ buildings, by enforcing the renovation of 3% of the cooled/heated floor to meet the
standards set by Article 4 of Directive 2010/31/EU. This measure applies to buildings owned and occupied by every Member State’s central government that have a total useful floor area greater than 500 m². As from 9 July 2015, this threshold shall be lowered to 250 m².

The same requirements will affect buildings occupied by administrations one level below the central government in case the concerned State extends this measure to said administrations.

Member States will encourage regional or local public bodies to apply energy efficiency plans by or without putting in place energy management systems or using ESCos, in order to achieve specific energy savings and objectives.

Member States shall ensure that central governments purchase only high-efficiency products, services and buildings, if possible taking into account cost-effectiveness and general feasibility. This applies to Data Centres that provide services for public administrations.

- **Smart metering and power metering**

  Smart meters are currently being deployed in several EU countries. They differ from traditional meters in the fact that they monitor consumption in short time intervals, and are capable of two-way communication. These devices play a key role in the development of demand response strategies.

  In relation to electricity, Member States shall ensure at least 80% of electricity consumers will be equipped with intelligent metering systems (smart meters) by 2020. In relation to gas, there is no obligation, but Member States or any competent authority they designate, should prepare a timetable for the implementation of them.

  Regarding the measurement of heating, Member States will guarantee individual power meters for each consumer when technically feasible and if expected savings justify the investment, in order to accurately reflect energy consumption, and to provide real-time information on energy usage. It is common for buildings to be equipped with single power meters in buildings that rely on centralized heating or cooling infrastructure. Individual power meters encourage efficiency in energy usage.

  The setting-up of individual meters will be compulsory in all cases for new buildings or whenever an existing building suffers important modifications which affect the energy infrastructure of the building. (Article 9) In the case of a substitution of the existing meter, individual counters will be put into place whenever the expected savings justify the investment required to install said individual meters.

- **Access to energy data**

  All consumers will be guaranteed access to data on their historical energy usage. Billing data for the last three years (or for the period starting when the supply contract was established, if said period is shorter) must be available. Furthermore, detailed information on daily, weekly monthly and/or yearly data must be accessible through the meter’s user interface or through the Internet.

  Access to existing historical data on the consumer’s energy usage will be granted to ESCOs, aggregators or other third parties nominated by the consumer, in order to increase the opportunities for the consumers to take action taking into account consumption and billing information, thus providing a mechanism to reduce or shift consumption, resulting in energy savings in both final consumption and, through the more optimal use of networks and generation assets, in energy generation, transmission and distribution.

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4 On the energy performance of buildings
Member States will compel energy retailers to provide, if demanded, data and estimations on cost of energy to consumers, in order to increase their level of information and ability to compare suppliers and offers.

**Energy efficiency obligations for energy distributors/retailers**

Member States will establish obligation schemes for energy distributors and/or retailers, through which they will be required to achieve cumulative, certified savings by 2020. These savings will be gradual, at a minimum yearly rate of 1.5% of the total energy volume sold/distributed to the end-users. This will encourage energy companies to foster efficiency improvements, by providing their customers with energy services or financing.

**Demand response incentives**

Member States shall aim their actions in market regulation at increasing overall efficiency, by eliminating incentives that prevent demand-side resources from participating in the balancing and capacity markets.

They will ensure a level playing field so that all resources can compete based only on their technical capabilities. In order to do so, market regulators shall define technical requirements and descriptions that include demand-side resources such as aggregators. Such competition between supply and demand-side service providers will further competence in the market and benefit the most efficient solutions – the most efficient solution will be used for each specific situation.

**Energy Services**

Member States shall foster an energy services market, in order to increase opportunities for consumers (especially SMEs) to take action in increasing their efficiency and achieving economic savings in doing so.

To this end, Member States will provide access to clear information on contractual aspects such as clauses that guarantee energy savings and clients’ rights, as well as economic incentives and financing mechanisms. Furthermore, Member States will publish and keep up-to-date a list of qualified and certified energy service providers, and report on the current and future energy services market. This way, potential users will be aware of available services and technologies.

Member States will promote the purchasing of energy services by public administrations, especially regarding building improvements, by facilitating contract models and information on ideal practices.

Obstacles – regulative or not – for the provision of energy services and the development of their markets will be removed, including actions by energy market players that may prevent energy services from becoming more wide-spread.

### II.1.1.d. Single European Energy Market

The European Union aims to build an internal electricity and gas market, in order to face economic and environmental challenges to come. The goal is to create a more flexible and secure system, which makes the transition to a low-carbon economy possible. A European internal market will increase competition and foster efficiency. However, investments in infrastructures must be made in order to improve trans-border connections in many parts of the EU.

European Directives 2009/72/CE and 2009/73/CE concerning common rules for the international markets in natural gas and electricity respectively, establish a common framework for trans-border trading. They are aimed at increasing market integration in the EU.

However, this is a complex challenge, as broad differences in the market structures and regulations between State Members currently exist. In the case of electricity markets, the
complexity of merging the two main approaches regarding how markets can be organized is worth noting. The two main types of market organizations are pool markets and balance-responsible entities.

In a pool-based market, agents make bids to the Market Operator for each of their plants individually. When the generating agent is also an electricity retailer, it must still purchase energy from the pool, thus making the retailer independent from the generator and therefore increasing competence in both wholesale and retail markets. Spain and Italy are the most important European countries that use a pool-based market.

On the other hand, in Central European countries such as Germany, France or the Netherlands, the design is based on the figure of the Balance Responsible Party. In these markets, each agent has a balance perimeter, made up by inputs (generation and imports) and outputs (retail sales and exports). Consequently, each agent send their net bids to the Market Operator, instead of performing individual bids for each of their plants.

A number of benefits will be obtained through the creation of a European integrated market. First of all, it is hoped that further liberalisation of national energy markets necessary to implement a single market increases the number of operating companies in each country, providing a wider choice for the consumers.

Stronger competition will lead to more competitive pricing, providing economic savings for users and contributing to keep manufacturing jobs within the EU by reducing business costs and therefore making European industries more competitive. A more flexible market could be achieved if retailers developed new tariffs to match every consumer's demand. Further liberalisation of the energy market will open up business opportunities in the demand side, while contributing to improve the efficiency in infrastructure utilisation.

Increased number of infrastructures across different countries may increase system flexibility, allowing for a higher penetration of intermittent RES, namely wind and solar energy, due to higher geographic diversification of generation (and storage) infrastructure which reduces variability in generation.

A more liberalised market with a greater number of players will lead to more liquid and transparent wholesale markets. Liquid markets with short-term price signals bring energy to where it is needed even if high demand was unexpected, thus increasing supply security.

At the moment, some EU countries already participate in regional electricity markets. For instance, Norway, Sweden, Finland, Denmark, Estonia and Lithuania are involved in the Nord Pool, while Germany, Austria, France, Belgium, the Netherlands and Luxembourg participate in the Central-Western European (CWE) market. The Irish Republic and Northern Ireland make up the Irish Single Electricity Market. These regional markets have proved to be efficient in increasing market liquidity and competition.

Regional markets tend to improve generating infrastructure utilisation when compared to national markets, and can help absorb high amounts of intermittent RES, which can be traded trans-nationally. Increasing the interconnection capacity between different countries enables the trading of excess energy, thus reducing location spread (market coupling) and avoiding losses of renewable energy due to excess supply.

In order to achieve the potential benefits of the internal European market, more must be done in terms of trans-border connection infrastructure, thus enabling greater amounts of energy to be transferred across countries. National legislations which regulate the energy markets should be harmonised in order to create a single, more competitive and liquid market.

II.1.2. Current Infrastructure

The EU’s energy infrastructure is not suited to match all the future energy challenges in Europe. Current infrastructure is based on a unidirectional chain of decision-making, with little exchange of information between generators and consumers. Although information from
producers is available for the system operator and in the wholesale markets, most of the consumers can’t have access in real-time to this information. In addition, distribution and transmission grids have no influence on consumption. System operators, therefore, can only contribute to the correct functioning of the grid by managing infrastructure to ensure supply meets demand.

On the contrary, a Smart Grid provides detailed, two-way information on loads and generation, allowing for better grid operation, and empowering energy consumers to act on information from the grid (Demand Side Response). Informed consumers may contribute to better balance the grid if incentives are provided. The following scheme below represents how the electrical grid is currently controlled. Current energy systems are based on mainly centralised generation, away from consumption spots, and directly connected to the transmission grid. Energy is transported over long distances in high voltage in order to reduce losses by Joule Effect. However, energy is generally consumed at medium voltage (large/medium consumers) or low voltage (small/medium consumers). Therefore, it is necessary to transform its voltage several times from generation to consumption.

![Current infrastructure](image)

**Figure 7 – Current infrastructure [SSG01]**

The following table shows, as an example, the average expected losses depending on the voltage level for the Spanish grid:

<table>
<thead>
<tr>
<th>Voltage Level</th>
<th>Losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 1 \text{ kV}$</td>
<td>13.61</td>
</tr>
<tr>
<td>$1 &lt; \text{kV} \leq 36$</td>
<td>6.00</td>
</tr>
<tr>
<td>$36 &lt; \text{kV} \leq 72.5$</td>
<td>4.00</td>
</tr>
<tr>
<td>$72.5 &lt; \text{kV} \leq 145$</td>
<td>3.00</td>
</tr>
<tr>
<td>$&gt; 145 \text{ kV}$</td>
<td>1.62</td>
</tr>
</tbody>
</table>

**Table 1 – Average expected losses [SMO14]**
Smaller power plants closer to end-users (distributed generation) are generally connected to the distribution network. In some cases, e.g.: when the end-user owns generation assets, these can be directly connected to the end-user (for self-consumption and/or trading with the grid).

In order to continually balance generation and consumption, important information flows must be transferred between consumers, grid operators and generators.

The market operator manages bids and offers by generation agents and large consumers or retailers to ensure supply meets demand. Said retailers make offers based on the forecasted consumption of their clients. Current communications from consumers to grid operators are mostly unidirectional: operators have information on end-users' consumptions, but have no influence on them (only some exceptions in few cases as large industries).

II.2. Data Centre Framework in Europe

II.2.1. Relevant Data Centre Legislation

Today, sustainability is a key aspect in many areas. To develop efficient and effectively projects is a must, as also is their commitment towards our environment.

Future data centres need to be aligned with those objectives which, in terms of energy consumption, turn into two different but compatible lines of activity: on one side, it is necessary to increase energy efficiency on data centres by using more efficient hardware and by improving data centre’s designs to achieve a better PUE. In other words, "amount of energy" to carry out work. On the other side, it is necessary to increase the usage of cleaner and renewable energies to diminish CO2 emission. In other words, “quality of energy” used.

Those two activities are needed in order to get more environmentally friendly data centres. However, there is a big difference in those two lines of activity: in the first one, the benefit for the management body is obvious and immediate. Less energy consumption means less operative costs, and so a more market-competitive product. Therefore, the interest of the European Commission fits with the sector itself.

Regarding the second line (quality of energy), however, return for managing bodies is not so obvious or direct, beyond the satisfaction of “well done work” towards a more sustainable environment. Not enough, often, when in the business world. So we have two main activities: one of them, seems to be enough attractive to DC managers due the savings it generates. The second, however, is not so directly beneficial, and therefore maybe should be somehow fostered.

Curiously, however, the search for energy efficiency (amount) is essentially the path that has being more institutionally supported, not considering the quality of used energy. Britain has today a green tax exemption for shared (colocation) data centres [GOV14]: to qualify for a break that effectively cuts energy costs, organisations must increase their energy efficiency. As, unlike other business sectors, data centres don’t have measurable outputs, industry group TechUK convinced the Department of Energy and Climate Change to measure this efficiency using the industry standard, PUE, which doesn’t consider the quality of the energy used.

At European level, the European Commission has already established a Code of Conduct on Data Centres’ Energy Efficiency, basically a voluntary compliance measures compendium towards more efficient data centres infrastructures, again mostly in terms of amount of energy used [COC14].

It should be mentioned at this point that European Union has carbon reduction targets. Greenhouse gas emissions should be by 2020 reduced by 20% compared to 1990; the share of renewable energy sources in final energy consumption should be increased to 20%; Energy efficiency should improve by 20%. However, this is not directly related to DC industry.
Today, for the industry a PUE of 1.5 it’s a “standard”, although some companies shown much better numbers (Facebook four main data centres had on 2013 a PUE of 1.09). So, there is still enough activity to be done to improve PUE. And, driven by the costs, DC managers will do that in order to keep their services competitive.

So, advancing towards more efficient DC is a reality and will help EC to reach their targets. But, on the other hand. EC is today going further on green objectives: DG CONNECT, under unit H.5 (Smart Cities & Sustainability) in Directorate H (Sustainable & Secure Society), aims to get Resource-Efficient Infrastructures, and establishes some targets regarding “quality” of used energy. Among them, regarding DC energy supply, defines a couple of objectives: 40% less of energy consumption, 80% use of renewables energies (by 2020). So, we need to consider more than just PUE, we need to talk about the quality/kind of the energy used.

Actually, the Green Grid, the organisation responsible for developing the PUE, has also announced other metrics that could be used to monitorize/reward/legislate:

- The Green Energy Coefficient quantifies the portion of a facility’s energy that comes from green sources. The metric is computed as green energy consumed by the data centre (kWh) divided by total energy consumed by the data centre (kWh).
- The Energy Reuse Factor identifies the portion of energy that is exported for reuse outside of the data centre. ERF is computed as reuse energy divided by total energy consumed by the data centre.
- Finally, Carbon Usage Effectiveness enables an assessment of the total greenhouse gas emissions of a data centre relative to its IT energy consumption. CUE is computed as the total carbon dioxide emission equivalents (CO2eq) from the energy consumption of the facility divided by the total IT energy consumption.

It seems that, on 2014 (April), DG CONNECT met with industry bodies to discuss the options for regulations about energy use in data centres.

According to the EC objectives, future DC need to be more sustainable improving PUE (a self-rewarding strategy DC managers are already working hard on due to the cost related direct benefits), but also usage of renewables should be improved. Today, there is a lack of legislation neither for energy efficiency or renewables usage aimed at DC sector, but if we expect to reach the already mentioned EC objectives, we need some kind of “reward” to foster this, especially regarding renewables usage, like on Directive 2010/31/EU on the energy performance on buildings.

DC legislation in Europe nowadays exists only with regards to data protection and waste in DCs, but to our knowing, apart from voluntary approaches there is no mandatory energy based Legislation. This lack of legislation hampers the current market penetration of a DC4Cities based tool substantially.

II.2.2. General Market Structure

It is important to look at the general market structure taking the relevant market dimensions for the DC4Cities offering into account. Therefore following dimensions are considered for the segmentation of data centres: green vs other data centres, services offering, geographical location, private vs public data centres.

II.2.2.a. Green data centre market structure

The green data centre market in Europe is estimated to grow from around $4.41 billion in 2014 to $13.48 billion by 2019, at a CAGR of 25.0% from 2014 to 2019. The U.K. is the biggest market in the European green data centre market. This market is segmented on the

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5 http://ec.europa.eu/justice/data-protection/
6 http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/legislation
basis of solutions of green data centre, such as servers, networking, power, cooling, and management software. The DC4Cities solution is part of the green data centre management software category. A market of a significant size can be addressed in Europe.

The characteristics of Europe Green Data Centre (GDC) includes the usage of renewable energy resources, use of standardized procedures which complies with the environmental regulations, use of minimum power consumption, and utilization of effective operational process. The Europe Green Data Centre (GDC) Market is showing growth and future opportunities due to the environmental concerns from the governing bodies which are forcing the companies to adopt green technology.

Also internal data centres of big companies are often subject to Green IT guidelines like a high share of renewable energy – which regularly means that the data centre either has on-site renewable generation or buys energy with a "renewable certificate" from their retailer. It regularly does not mean that the power profile of the data centre is adjusted to the supply of renewable energy. The cost of this green energy is often an investment of the mother company into Corporate Social Responsibility and cross-financed: The German SAP for instance announced in March 2014 that it will run all its data centres with 100% renewable energy.

II.2.2.c. Geographical location

The location of the data centres is made available on the Data Center Map in Figure 9. This maps allows to see per geographic area the different data centres. This map is an interesting instrument for identifying the ones located in urban areas which is the target of the DC4Cities solution.

"On a worldwide basis, Canalys anticipates data centre IT infrastructure end-user revenue to
grow by an average of 7% each year, to reach $149 billion by 2015, up from $107 billion last year. EMEA is expected to account for 27% of the global value, with other regions – notably Asia Pacific – poised to expand at faster rates." [CAN01]

The map also shows that there is a dichotomy which might further polarize in the next decades: huge data centres outside cities, located directly at favourable conditions like local cooling ("Iceland") and nearly unlimited amounts of low-cost power (e.g. hydro in Sweden or other Northern countries) on the one hand and small to medium sized data centres in the vicinity of cities (all of them being smart) because of the necessity of data protection or low latency. Examples for the former can be found in the map of Ireland, Iceland, Sweden and Norway – the latter a scattered everywhere in Europe. Analysing today’s map also shows that (huge) cloud data centres belong more to the first category, whereas the second category comprises all kinds of data centres.

Figure 9 Data Centre Map overview [DCM01]

II.2.2.d. Public vs. private data centres

Data centres can be public or private from different point of views. Public or private can refer to the data centre being owned by a public or a private organisation or it can refer to the data centre having resources shared by a single or by multiple organisations. The tendency for
data centres owned by public organisations as well as single-user or multi-users data centres is to use more and more cloud-based solutions.

According to vendors such as Dell, there is a data centre consolidation ongoing in the public sector such as government, education and health. This is due to the changes in the amount of funding which lead to operational cost reductions. Moving services to the cloud is a common way for public organisations to reduce such infrastructure costs.

As publically owned DCs are subject to GreenIT guidelines of a smart city, they are an important market for DC4Cities. The public organisations have been or will be moving their services more and more to the public cloud. So, considering the already explained EC objectives regarding future DC and their energy supply, they are by definition part of the D4Cities target, as they must concern about the kind of energies used. Another favourable circumstance of public data centres or data centres that process public data is that their customers in most cases are a so-called “captive audience”, meaning, they will most probably not leave the city in case the service level is impacted in some time slots by DC4Cities policies.

On the other hand, private companies should also be interested on provide more environmentally friendly IT services. First, increasing energy efficiency, just in order to keep their services competitive. This is a must for them. But, secondly, they also need to concern about the kind of energy used, as this has every day more impact on their brand image, as for instance is clearly shown by the [GRE14], where a Rackspace manager, asked why the committed to 100% green energy states: “Our customers simply expect green energy.” [GRE14,p.30].

A multi-users data centre provides ICT resources such as storage and servers which are shared by several organisations while a single-user data centre is composed of ICT physical resources which are used and accessed by a single organisation. It provides organisations control and privacy. Infrastructure as a Service (IaaS) and Platform as a Service (PaaS) offerings are most often offered by multi-users data centres but they can as well exist in single-user data centres.

DC4Cities can be offered to add flexibility in both single-user and multi-users data centres. Single-user data centres will limit the risk for impacting the quality of services offered to other organisations. In the case of multi-users data centres all the organisations will have their services becoming energy adaptive when introducing DC4Cities in such data centres. This will require a more cautious verification of the SLAs offered to the different organisations.

Figure 10 - Growth Rates of Public Cloud Services Market [GGC01]
According to Gartner [GAN07] the global spending on public cloud services (that means not publically owned data centres but rather multi-user data centres) is expected to grow 18.6% in 2012 to $110.3B, achieving a CAGR of 17.7% from 2011 through 2016. The total market is expected to grow from $76.9B in 2010 to $210B in 2016. 24% of all new spending on cloud computing services will originate from Western Europe.

Anyway, as has been previously said, some background should be provided in order to make renewals adoption more attractive for private companies. Should this background somehow foster the adoption of renewals, DC4Cities solution will be more suitable for them.

### II.2.3. Environmental Impact of Data Centres

Digital devices have become a necessary part of our lives. They provide a medium of real time and on demand access to a variety of online content and hundreds of service offerings from businesses across the globe.

Estimated 2.5 billion people are connected to the internet throughout the world. Life without it is unimaginable. It has changed the way we communicate with each other, work and entertain ourselves.

![Figure 11 - Data Growth Rate](image)

The spread of the internet has led to the ever growing emergence of new businesses which provide innovative services, are disrupting in nature and often replace long-standing business models and industries. It is expected that this trend will accelerate further in the near future as the global online population increases. The number of mobile phones reaches 50% of the world’s projected population, increasing from 2.3 billion in 2012 to an estimated 3.6 billion by 2017. [CIN13]

Another factor in the growth of data generation is that companies are treating data with the same importance as labour and capital [MKR11], as a study by McKinsey Global Institute points out. Consequently, these organizations now focus on Big Data analytics, which includes processing computing intensive unstructured data streams rapidly and constantly from sources such as web sites, mobile devices, cameras, and software logs. The data is heterogeneous and variable in nature and comes in many formats, including text, document, image, video, and sensed data and requires massive amount of computing power.

Furthermore, a study by Clipperton [CFD14], predicts that due to further proliferation of the digital lifestyle, the internet traffic would see a combined annual growth rate of 24% from 2012 onwards till 2017 (see Figure 11 above). The internet and therefore cloud computing which comprises the data centres and networks part of it, has thus become the foundation of the global economy.
II.2.3.a. IV.2.4.2 Increasing Energy Footprint

Lot of energy is required to power the vast online world we have created, but it is difficult to make a good estimation of the energy consumption by the internet. The estimation is difficult, because of the fast paced growth in data generation, a wide range of devices and energy sources, as well as rapidly changing technology and business models.

Internet traffic mostly comprises of data which is generated by the service users of various business and requires storage, networking and processing resources, either at the client side or at the server side, or both. Therefore, growth is seen across all the three components of the internet system namely end user devices, networks and data centres.

It has been observed that there has been a relative shift in the energy footprint share within the three parts that comprise the internet. The share of data centres and networking has grown, which is consistent with the ongoing growth of the internet-based computing and shift to thin client devices such as tablets.

![The Cloud's Growth: A Breakdown](image)

Figure 12 - Clouds Growth: A Breakdown [STR12]

Also, it is predicted in the most comprehensive report on the internet’s energy demand, the SMARTer report (2012) [STR12] - data centres would be the fastest growing part of the internet system in terms of energy consumption. The report also stated that, the data centre share of the energy consumption by the internet in total, would increase to 23% by the year 2020, while the end devices share would decline to 53% from the current share in 2011 at 61%.

Furthermore, it can be estimated based on the analysis in the SMARTer 2020 that the global aggregated electricity demand of the cloud in 2011 was 684 Billion kWh [CED14]. In order to get an idea how much energy the cloud consumes, only a comparison with other major electrical energy consumers reveals the scale of the impact the cloud has. When compared with the electricity demand of countries in the year 2011, cloud is ranked 6th (Figure 12) and consumes more than Countries like Germany or Canada. It is expected that the electricity demand of cloud computing will increase by more than 50% by the year 2020, keeping in mind the current growth rate of data.
As already mentioned in the preceding sections and paragraphs, that all parts of the internet system require electrical power to run on and in quite substantial amounts in today’s digital broadband arena. As electricity is produced using different types of fuel sources, which then are consumed, produce a wide range of values of GHG emissions/ KwH of electrical power produced.

The Kyoto Protocol covers six GHGs, namely carbon monoxide, methane, and nitrogen oxide besides carbon dioxide. But because carbon dioxide is by far the largest GHG emitted by volume, representing about 80% of these GHGs associated with airborne pollution [RER13]. (Conor Kelly, 2011) It is pertinent to give it utmost attention. Furthermore, CO2 is subjected to emission taxes and trading and therefore has the largest financial implications for all the stake holders involved, energy suppliers, regulators and consumers.

Greenhouse gases are produced in order to generate the electricity needed by the data centre. Hence, emissions are not directly emitted by the data centre, but indirectly by the power needed to operate the data centre. Therefore, the fuel source used in generating the electrical power now becomes the main point of further discussion.

According to Figure 14, most CO2 is produced by coal-fired power plants. Next comes the power plants that use either Diesel or Furnace oil to the production of electrical power.

Data centres classified as Tier 2 and above, that comply with certification requirements, have backup generators which run on diesel fuel. These diesel generators are used in case if the main power supply from the grid fails.

As it can be inferred from the previous discussion, that the degree to which the IT’s impact in general and data centres in particular, on CO2 emissions, can be measured precisely is quite low. It is mainly because of the lack of transparency by the major IT companies and data centre operators involved in the internet value chain. This is partly due to not wanting to disclose information which might be used by the competitors for business advantage. The other one is to protect the favourable image of the IT industry, that of a clean one, as currently perceived by the public. There has been some estimations of the carbon footprint, which have been diverse and wide ranging in their ways and methods of assessment. The
most widely accepted method of assessment was published in 2008, in the SMART 2020 report.

![Greenhouse Gas Emissions of Electricity Sources](image)

**Figure 14 - CO2 emissions by Fuel Source for Electricity Generation [RER13]**

The report estimates the CO2 emissions of IT sector in the year 2011 at 2% of global emission levels, or 830 MtCO2e (Million Tonnes Carbon Dioxide equivalent).

It also predicted that by 2020, the overall CO2 emissions by IT would rise to 1,430 MtCO2e, with the networking and telecom component having the largest share of 815 MtCO2e, followed by data centres with 358 MtCO2e (Figure 15).

![Estimated CO2 emissions](image)

**Figure 15 - Estimated CO2 emissions [SRT11]**
In the latest update of this same report estimates that the data centres’ CO2 emissions growth rate would decrease to 7.1 % till 2020, from the previous decade’s rate of 9%. This predicted growth would take the data centres’ carbon footprint up to 0.29 GtCO2e, despite several technological developments – such as virtualization of servers and improvement in cooling technologies, which helps in lowering the PUE of the data centre. Any further technology or measures related to the energy efficiency would further reduce the CO2 emissions by the data centres [SMT12].

However, it is estimated that most large data centres, which form the global backbone of the Internet, can on average slash their greenhouse gas emissions by 88 percent [STN13]. They can do this in a variety of ways which include switching to efficient, off-the-shelf equipment and improving energy management. However a readily available and easy to implement approach is the use of renewable energy sources by these data centres coupled with the use of mechanisms and tools to manage their computational loads in accordance with the level of sourcing electricity from renewable sources like wind and solar power, sources which feed into the grid which power them. One such approach successfully demonstrated previously in an experimental trial, is All4Green with GreenSLAs, which is now slowly being adopted within the DC industry.

II.2.4. Suitable Data Centres

II.2.4.a. Business Models

There exists a plethora of business models in data centres, and the same applies to business model taxonomies. Business models are differentiated according to the customer group, the revenue flows, the traded item, key activities or by a combination or two or more of these differentiation criteria [ABD11] [HAR14] [RAP04] [RAT11]. From the point of view of data centres suitable for DC4Cities, the question of flexibility is the most important as DC4Cities solutions aim among others at a dynamic scheduling.

On the other hand, flexibility is directly related to the level of control that the data centre has with respect to the operation of the data centre (and thus the IT service). So, it suggests itself to differentiate according to the item traded and the question to which degree the operation of the DC is outsourced. The level of control or the outsourcing factor of a DC has a huge impact on its suitability for DC4Cities: The more outsourced the IT service operation is, i.e. the higher the level of operation control by the DC as outsourced company, the more flexible a DC is and thus the easier it can participate in a DC4Cities based scheme. Figure 17 sorts the main DC business models according to the control by the DC.
DC4Cities solution suitability depends on IT services provided, as shown on the figure. For instance, on Co-location services, the decision on when to use the provided infrastructure is not on DC manager’s hand (but maybe for some vending strategies). Similarly, Supercomputing data centres need to, in order to be competitive, keep their high performance computers continuously working, near a 80% of their capacity, and so scheduling works according to external inputs is also not an easy work.

Otherwise, IaaS, PaaS or SaaS (or even newer BPaaS - Business Process-as-a-Service) are more suitable to use DC4cities solution, as part of the tasks that conform the IT service (for instance, the ones related to maintenance jobs, databases consolidation, content indexing, back up, etc.) can be scheduled. As explained before, the more of the control over the whole solution (i.e. IT Service seen as a whole) the DC manager has, the better suitability for the DC4Cities software.

However, not only the business model impacts the flexibility with which a DC can follow the patterns of wind and sun. Another major influencing factor is the rigidity of SLAs: basically, the more rigid SLAs, the less likely it is for a DC to be able to actively shape its power demand. However, there are SLA parameters that are more important – or more limiting – from the point of view of DC4Cities and others that are less restricting.

Usually, availability of the IT Service is the most important SLA parameter, but also capacity is relevant, or how fast a required change is deployed, for instance to increase hardware resources. Anyway, the definition of how those parameters (and specially availability) are defined and measured depends mainly on the IT service design, and of course this design has great relation with the kind of service it is related to (IaaS, PaaS, etc.). But we need to consider, for instance, that some co-location IT services may have flexible availability SLAs (for example, for an external back up copy service the remote system could try to connect different times, and the DC using DC4Cities software in which the storage system is located could decide when to turn on it). Worth it? Depends on the business model: as a DC manager, using DC4Cities Software I could provide cheaper services in exchange for flexibility.

Similarly, supercomputing resources can be offered at different rates according to the accepted time-to-execution requested. More flexible SLA allows data centre manager to
schedule jobs according to external inputs, although, as explained before, the processors should be working at 80% of their capacity.

At BPaaS or SaaS levels, access should be granted at a high availability level, at least during working hours, but there are back-end processes that could consider more or less flexibility (again, providing the service at a different rates) according to DC4Cities scenario.

![SLA Flexibility Diagram](image)

*Figure 18 – SLA Flexibility*

Together, these two criteria can be sorted to give an idea to which degree a DC can participate in a DC4Cities scheme or not, according to the IT services it provides. Figure 18 shows examples as to these criteria for DC4Cities according to the dimensions “SLA flexibility” and “Outsourcing factor”: A mission critical high-performance focused data centre can only theoretically schedule batch jobs according to a volatile energy supply – very tight SLAs with regards to access and performance refrain the DC from taking part in DC4Cities (red bubble). However, if a DC offers SaaS it has a higher degree of freedom to manage the DC in an eco-aware way, especially if it has a high percentage of GreenSLA based services (orange/greenish bubble). Regarding application hosting, the DC management also has a rather high degree of freedom – but the choice of applications running in the DC is up to the customers. And as there are applications that are more and others that are less susceptible to manipulation with regards to their power profile, the DC’s DC4Cities opportunities are reduced in comparison with the flexible SLA SaaS case. The same applies for co-location hosting: there are many different sub-sets of business models with a higher or lesser hard- and software management share of the co-locating DC and accordingly higher or lower DC4Cities participation options – however, the more flexible the SLA, the easier it is for the DC to shape its power load. Of course these two parameters “outsourcing factor” and “SLA flexibility” are inter-related – the less flexible a business model the less flexible the SLAs will probably be. But one business model can along with various levels of SLA flexibility as the tendency to having bronze, silver and gold SLAs shows.

Having identified basic parameters in business models that increase the flexibility of a DC and thus its opportunities to follow intermittent energy sources, a general market size for these business models should be determined for Europe. This could give a first indication as to how the chances to market DC4Cities under current conditions are in Europe.
II.3. Smart Cities in Europe

II.3.1. Smart Cities Roadmap

"If the "If the nineteenth century was the century of empires and the twentieth century the century of nation states, then the twenty-first century will be the century of cities"\(^8\).

It is not an easy task to define the smart city concept, because we can find various definitions both in academic literature and urban practice. In our deliverable D2.1 there is a section where we do a review of the different definitions and the goals that arise from each definition which resulted in the following smart city definition tailored to the DC4Cities project:

<table>
<thead>
<tr>
<th>In the context of DC4Cities a smart city is a city that connects the electricity infrastructure, the IT infrastructure and the business infrastructure of IT services in a way that</th>
</tr>
</thead>
<tbody>
<tr>
<td>- citizens are sufficiently supplied with smart commercial and public IT services</td>
</tr>
<tr>
<td>- data centres are empowered to utilize renewable electricity sources at a the maximal level possible from the part of the physical renewable power production infrastructure (target: 80%).</td>
</tr>
</tbody>
</table>

To achieve this, the smart city authority has the fundamental role of reconciling the wishes of the data centres and the citizens with the constraints of the renewable electricity production to the greatest possible degree by

- Leveraging information to make better decisions
- Anticipating and resolving problems proactively
- Coordinating resources to operate more efficiently

Smart Cities, roughly speaking, combine diverse technologies to reduce their environmental impact and offer citizens better lives. To achieve this goal is not only a technical challenge. Organisational change in governments and society is essential. Making a city smart is therefore a very multidisciplinary challenge, bringing together city officials, innovative suppliers, national and EU policymakers, academics and civil society.

Giffinger [GIF07] enumerates a set of characteristics which represent a starting point to not only understand the smart city concept but also for the evaluation of today’s cities with respect to their smartness. Basically, he divides in six the categories or dimensions that define every smart city. These dimensions are:

1. Smart Governance: It includes public, private and civil organizations. Its goal is to bring closer governments and citizens, facilitating the accesses to the public services and assuring the transparency in the decision making.
2. Smart Economy: Its objectives are to increase productivity in a sustainable way through e-business processes and e-commerce.
3. Smart People: It means to promote creativity, innovation and critical thinking through the use of technology.
4. Smart Mobility: Its objective is to develop infrastructure for logistics systems and integrated transport using green energy.

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\(^8\) Former US Conference of Mayors’ President and Denver Mayor Wellington E. Webb, First Transatlantic Summit of Mayors in Lyon, France, April 6, 2000.
5. Smart Living: Its goal is to develop applications and technologies for enabling responsible life styles, behaviour and consumption.
6. Smart Environment: This means having the necessary technology to manage efficiently the energy consumption and to promote the use of the renewable energy.

**Figure 19 - The six smart dimensions**

In the last years it is not possible to understand the economic and social development of any region without the impulse of the cities. They are in charge of promoting social, cultural and economic progress and innovation.

The demographic concentration, which the cities have experienced, has turned them into the ideal stage where to confront big challenges as sustainability. As example, more than two-thirds of the world’s energy is consumed in the cities and they emit 70 percent of global emissions of CO2.

And the trend in the coming years, if we maintain the current consumption model, says that in the year 2030 the world will need 50% more food, 45% more energy, and 30% more water. We can extract another indicative of the current situation from the mobility, according to the data available to the European Union: In the same year, 2030, private car fleet will have depleted CO2 emission quotas permitted.

There are many studies with different points of view on stocks of non-renewable energy reserves, but everyone agrees that these energy sources are finite. In some of that studies estimate that these kind of energy reserves (coal, oil, gas and uranium) could be exhausted before 2070. UN-Habitat, in its report on "Cities and climate change" [UNH11], notes the negative impact on the quality of life and economic and social instability caused by this population growth. To this we should add the changing climatic conditions.

The concept of the smart city is really a framework: a way to fulfil a vision of modern urban development that can vary profoundly from place to place. That’s why no two smart cities are bound to be exactly the same. However it is common the notion that ‘smartness’ enhances virtually every dimension of city life: from democracy, healthcare and education to the economy and environmental sustainability. The challenge for governments, private industry, non-governmental organizations (NGOs) and other stakeholders is to collectively determine
how to realize a smart city vision that meets their needs and accords with their local values [ALC11].

Balance between the production and the consumption of the resources, in addition to an efficient use of these resources, are therefore the challenges that the cities should assume and to this target the strategy of Smart City is aligned. Some cities, like the city of Stockholm, have already subjected themselves to an energy and smart city road map that includes CO₂ reduction targets like the city of Amsterdam that aims at a reduction of 40% with respect to 1990 [AMS13].

For helping all these stakeholders, the European Commission launched the Smart Cities and Communities European Innovation Partnership⁹. Its purpose is to pool resources to support the improvement of energy, transport and information and communication technologies (ICT) in urban area. The European Commission aims to deploy a small number of projects which will be implemented in partnership with cities. For 2013 alone, € 365 million in EU funds have been earmarked for these types of urban technology solutions. The smart cities and communities stakeholders platform is one outcome of this approach¹⁰.

The legal basis for this can be found in the Digital Agenda¹¹ for Europe as part of the urban and regional dimension of the Europe 2020 strategy [ECO11] and SETIS¹², the European Strategic Energy Technologies Information System that also builds on existing legislation like CIVITAS. Europe 2020 strategy sets out five targets as shown in Figure 20:

![Headline Targets](image)

**Figure 20 - Energy 2020 targets**

The European smart city roadmap as an integral part of the Europe 2020 strategy is was laid out in the technology roadmap of the SET plan and aims at having 25-30 European cities with more than 500.000 inhabitants on the verge of becoming low-carbon cities by 2020 [ECS09]. The milestones of the roadmap and the Smart Cities Initiative as part of this roadmap can be seen in Figure 21. DC4Cities is a project that fosters the energy network related goals to improve energy management in cities, therefore, it would be part of the set of initiatives within the area of electricity that appear in this graph.

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¹⁰ [http://eu-smartcities.eu/about](http://eu-smartcities.eu/about)
As we have seen, the implementation of the model of a Smart City as defined in [GIF07] or D2.1 is complex because it affects to practically all the services of the city, requires a cross-sectional view, involves transformations of the urban infrastructure and changes in the models of management. This complexity, that will be different for each case, it implies that the roadmap for each city, in addition to establishing the necessary steps, keep in mind the actors involved, the calendar and the sources of funding.

While all roadmap presents common elements and a common purpose, the starting point for each city will be different as well as their priorities, and therefore also the resulting roadmap.

Therefore we see as the roadmap will not be the same in a newly created city that in an existing city where you must take into account the urbanistic transformations or traffic. And neither will it be the same between cities that already have existing projects in certain sectors, but not have developed projects in others. In any case, the goal of all roadmap will be the availability of an interconnected system that will take advantage of this inter-relation to optimize resources and facilitate the use of all of this information to the citizens.
Within the Smart City scope, each city has prioritized its performances according to its idiosyncrasy. In this sense, Barcelona has based its initiatives on a strong adoption of the ICT and on the conception of the urban model of self-sufficient neighborhoods. Malaga and Amsterdam have given a strong impulse to energy improvement initiatives resulting from the involvement of generation and power distribution companies. Madrid and Stockholm have focused on aspects of improving public safety and intelligent traffic management. Santander and Goteborg have been based on the development of an infrastructure of sensors of communication that enables the monitoring and continuous control of the city [CTC12].

II.3.2. Smart Cities Infrastructure

During the last decade, a lot of strategies calling for digital, innovative, sustainable etc. cities have been elaborated in order to answer to the challenges posed by the global urbanization. The smart city model as e.g. defined in [GIF07] and adopted by the EU in [EUP14] has crystallized as unifying concept.

We have seen that building a Smart City affects all services provided in the city: mobility, production and distribution of urban services (energy, water, etc.), education, health, emergencies, security, etc. The set of all systems created for the provision of these services is what we know as the infrastructure of the city. Smart City incorporates innovation, technology and intelligence to the basic infrastructure to develop a more efficient city, flexible and less expensive.

An important part of the infrastructure is already available, but the participation of the industry is necessary. Nowadays there are no measuring devices for all the observations we wish to measure and it is very essential the role and participation of the private sector. In fact, the projects of deployment of sensors are running today around the world and the innovations
are continuous. The knowledge of the market and the industry initiatives that are now rolling are also essentials.

Nowadays there are no measuring devices for all the observations we wish to measure. Here it plays an essential role the private sector, it is important to have energy service companies (ESCO) that be ready to assume the financial and technological risk that there need the projects of innovation and technological development.

Barcelona, however, in that respect is already advanced: It has a sensors platform with more than 2,000 sensors in an open source platform (linux, redis, mongodb, etc.) [PSB13] and a free public wifi network with more than 600 hotspots (http://www.bcn.cat/barcelonawifi/en/).

II.3.2.a. Data Processing

As important as having these sensors, devices and technologies of communication is the necessary infrastructure to store and treat the data collected. The large volume of information generated needs information systems with increased storage capacity and process.

Some concepts that are emerging with the new needs are [OTE12]:

- **Big Data (BD):** The use of large volumes of data will become a key base of the competition and the growth of future Smart Cities. From the point of view of the competitiveness, as soon as there was overcome the phase of digitization of the city, all the cities will have to take the information with special seriousness. To solve the problems of storage, management and processing within a reasonable time are developing a range of technologies like Hadoop.

- **Cloud Computing (CC):** It is possible to define the CC as a model to enable suitable access on demand to a shared set of configurable computing resources, for example, networks, servers, storage, applications, and services that can be rapidly provisioned and released with a minimum of effort by the service provider. An example of this kind of computing is Azure (Microsoft).

- **Internet of Things (IOT):** can be defined as a network of interconnected daily objects, localized, and with "intelligence". These objects would be provided with sensors and actuators connected through networks (wireless or cabled) that would allow them communicate with each other.

II.3.2.b. The Smart City IT Framework

As a summary, the Smart City becomes a great system with a similar architecture to any other information system: Data entry through devices such as sensors or smartphones. These data are collected and transferred through communications networks to large data bases. Before being consulted, these data are modified by processes that add valuable information to bring it to the platform services. In the service platform, we can use this information to make management decisions.

This framework is currently being developed in connection with Smart CityOS and iCity (see D2.1, IV.1).

According to the consulting firm Gartner [GAR11], Internet of things IoT technologies and the communications machine to machine M2M will take between 5 and 10 years to be used on a massive scale, being now in the definition phase and with a high level of expectations.

Other technologies such as networking mesh of sensors (Wireless Sensor Networks WSN), much more mature in its definition and with expectations according to their real possibilities, can still take much more.
The overview of the technology describes the phase in which we are: deciding which technology use, testing the real capabilities, and defining to philosophical level what we understand by intelligence of city and how it should be applied.

![Figure 23 - Gartner forecasts for the mass adoption of key technologies for the Smart City](GAR11)

**II.3.3. Smart Cities Suitable for DC4Cities**

The question is how to identify current and future smart cities. The IDC Energy Insights Smart Cities Maturity Model identifies three macro stages of maturity [IDC12]:

- **Scattered**: Cities that are developing projects for energy efficiency or to optimize the use of resources (for example, the introduction of intelligent systems of transport or energy consumption reduction). At this level, the services resulting from these projects are managed by the departmental structures as a series of isolated projects. Taking into account the level of maturity of the Smart City project, most of initiatives are in this state since they consist of isolated pilot projects to solve specific problems.

- **Integrated**: At this level, the initiatives are looking for synergies between them and collaboration in the management of projects is almost a requirement. The value obtained by the initiatives is greater than their simple sum since that value is completed by other initiatives. Already beginning to exist examples of cities at this stage where they are aligning different projects to achieve, beside as the ultimate goal of each project, a common goal to all of them. This is the case in Amsterdam where all of his projects are focused on the reduction of CO2 emissions.

- **Connected**: In this stage, all the projects are part of an integral main plan managed by a committee, which it includes in addition to the local government, the citizenship and the companies. This should be the final station of the roadmap of any city that assumes the challenges raised to Smart Cities. However, there is still no city with this complete implementation of all its “smarts” services. This is the great challenge, since it is a complex process of transformation, with impact on the public highway, in the urban furniture and in the buildings already constructed.
These three stages of maturity are further defined by two factors: data availability and its respective level of integration. The maturity model suggests that in the transformation process the level of coordination among all existing and planned initiatives might vary in relation to a city’s maturity. Therefore a smart city might not only be at different levels of maturity in different timeframes, but might also be simultaneously at different stages for each of the smartness dimensions.

According to these parameters, in Spain IDC identifies the following cities as top 10 for 2012: Barcelona, Santander, Madrid, Málaga, Bilbao, Valladolid, Zaragoza, Vitoria-Gasteiz, Donostia-San Sebastián, Pamplona/Iruña.

In Italy, for instance, according to the ICity Rate 2013 from FORUM PA, Trento and Bologna are the top smart cities. For obtaining this outcome, they have analysed about 100 indicators related to the critical issues and the strengths of the Italian cities. The first places are occupied by Trento, Bologna, Milan, Ravenna, Parma, Padua, Florence, Reggio Emilia, Turin and Venice [ICI13].

[EUP14] establishes four maturity levels, but in this case the maturity level is related to initiatives or projects instead of measurable facts like in the above cited study:

- maturity level 1: a Smart City strategy or policy only
- maturity level 2: a project plan or project vision, but no piloting or implementation
- maturity level 3: pilot testing Smart City initiatives
- maturity level 4: a Smart City with at least one fully launched or implemented Smart City initiative.

According to this ordering 240 of the EU-28 cities with 100,000 inhabitants and more qualified at least in one aspect as a smart city and were therefore classified as smart city [EUP14]. In this study, contrary to objective parameters, smart cities were ordered according to smart city policy initiative into four maturity levels and according to six characteristics regarding environment, mobility, governance, economy, people and living. The figure shows the number of cities qualifying as a smart city according to one or more of the characteristics: 34% of the cities had more than one smart city characteristic.

![Figure 24 - Smart Cities according to at least one of the six EU smart City Characteristic. Total > 240, because some qualified in more than one characteristic](image)
Fortunately the researchers of [EUP14] granted the DC4Cities consortium access to the created data base. Therefore it is possible to identify the 27 smart cities in Europe that are the smartest according to the parameter levels (level 4) and qualify according to the parameters “Smart governance” and “smart environment”. These two parameters seem to be the ones that mostly determine the requirements for the public data centres and are therefore ideal candidates for the first wave of DC4Cities marketing endeavours aimed at publically owned data centres in smart cities of today. The reason for the selection of these parameters is that they imply an increased use of city administration data processing. The other parameters are not necessarily related to public data processing, like smart mobility or smart living – those services may well be provided by private commercial data centres. “Smart environment” according to [GIF07] includes an awareness of renewable energy sources and thus aligns with the goals of DC4Cities.

Barcelona, the partner city of DC4Cities, is among these high potential candidates. In order to assess a market potential for DC4Cities, both under the current situation as well as in the envisioned DC4Cities future (about the decade of 2030), it is helpful to have more information about the power and cost requirements of the smartest European cities of 2014. This is why a section about the Barcelona case study was added. The following table identifies a sub-set of those European cities that today have committed themselves to the smart city concept and are attributed a smart city maturity level of four.

**Table 2: Smart Cities with level of maturity 4, smart government and smart energy initiatives [EUP14]**

<table>
<thead>
<tr>
<th>City</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam</td>
<td><a href="http://amsterdamsmartcity.com/projects">http://amsterdamsmartcity.com/projects</a></td>
</tr>
<tr>
<td>Athens</td>
<td><a href="http://www.peripheria.eu/about">http://www.peripheria.eu/about</a></td>
</tr>
<tr>
<td>Barcelona</td>
<td><a href="http://eu-smartcities.eu/place/barcelona">http://eu-smartcities.eu/place/barcelona</a></td>
</tr>
<tr>
<td>Berlin</td>
<td><a href="http://eu-smartcities.eu/content/addressing-capacity-analytical-financial-gaps-smart-cities">http://eu-smartcities.eu/content/addressing-capacity-analytical-financial-gaps-smart-cities</a></td>
</tr>
<tr>
<td>Bremen</td>
<td><a href="http://infrastructuresmartcities.blogspot.dk/2013/05/city-of-bremen-germany-cuts-energy.html">http://infrastructuresmartcities.blogspot.dk/2013/05/city-of-bremen-germany-cuts-energy.html</a></td>
</tr>
<tr>
<td>Cologne</td>
<td><a href="http://www.smartcity-koeln.de/projekte/">http://www.smartcity-koeln.de/projekte/</a></td>
</tr>
<tr>
<td>Linköping</td>
<td><a href="http://www.linkoping.se/Global/Milj%C3%B6%20och%20h%C3%A4ls%20och%20milj%C3%B6%20och%20h%C3%A4ls.html">http://www.linkoping.se/Global/Milj%C3%B6%20och%20h%C3%A4ls%20och%20milj%C3%B6%20och%20h%C3%A4ls.html</a></td>
</tr>
<tr>
<td>London</td>
<td><a href="http://eu-smartcities.eu/content/mass-retrofitting-equitable-and-inclusive-approach">http://eu-smartcities.eu/content/mass-retrofitting-equitable-and-inclusive-approach</a></td>
</tr>
<tr>
<td>Paris</td>
<td><a href="http://eu-smartcities.eu/place/paris">http://eu-smartcities.eu/place/paris</a></td>
</tr>
</tbody>
</table>
According to the concept of maturity that we find in [IDC12], it is important that it exists (or at least be in the roadmap) the definition of a connected system of smarts services. DC4Cities can take advantage of having all the correlated data and in turn can give more value to these data. Taking into account the objective of DC4Cities, energy efficiency and use of renewable energy, the more intelligent is the DC and its hosted services, the better results may obtain. At the same time, the data provided by DC4cities can offer more value to the rest of connected services, which can be an additional incentive to adopt the system DC4Cities.

Another aspect to take into account when defining the possible market for DC4Cities, is the commitment of the Smart Cities towards to the Open platforms. DC4Cities is built on an Open infrastructure and uses APIs with standard protocols in order to be able to easily integrate within any DC and any Smart City system. At this point the integration will be easier in those Smart Cities that are already developing its initiatives on open platforms and even more in those ones that have a high level of maturity (level 4 - connected Smart cities).

An example of Open platform initiative is Open Cities. Open Innovation is the standard in the private sector, however it is very difficult to apply it to the public sector and especially in aspects such as governance or incentives.

Validating how to approach Open Innovation methodologies to the Public Sector is the purpose of Open Cities, a project co-founded by the European Union. It will do so, by leveraging existing tools, trials and platforms in Crowdsourcing, Open Data, Fibre to the Home and Open Sensor Networks in seven major European cities: Helsinki, Berlin, Amsterdam, Paris, Rome, Barcelona and Bologna.

Main objectives:

- Open Innovation in the Public Sector. Explaining how Open Innovation can be applied to the Public Sector.
- Living Labs in Smart Cities: Urban Labs. Making use of Living Labs for promoting the innovation in Smart Cities.
- Pan European Platform. The creation of pan European platforms for Crowdsourcing, Open Data and Open Sensor Networks.
- Future Internet Services & Ideas. The delivery of Future Internet Services applications and ideas especially in the realm of mobile devices and Augmented Reality applications.

However, there are also other projects for a software framework in a smart city like iCity which aims at providing a framework for third parties making use of the abundance of city-related data. The environmental aspect does not have the importance as it has in the European smart cities identified in [EUP14]; nonetheless the general inclination towards the ICT based management of the city is obvious. Members of this platform are: Barcelona, Genova, Bologna, Cornella de Llobregat, Lamia, London, Zaragoza, Manchester, Milano.

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13 http://www.opencities.net/content/project
14 http://www.icityproject.eu
Piazenca, Reggio Emilia, Torino, Berlin. As can be seen there is a high overlap with before mentioned groups.

In conclusion, taking into account the data provided, Smart cities suitable for DC4Cities would be cities with a number of citizens greater than 100,000, with initiatives already advanced in the six characteristics listed above, especially in Smart government and Smart energy.

The commitment to open platforms and the fact of having a system of smart systems, beyond vertical initiatives, will be aspects that can contribute to the success of DC4Cities. Therefore, the cities Helsinki, Berlin, Amsterdam, Paris, Rome, Barcelona, Bologna, London, Manchester, Milano can be a good starting point as they belong to both, one of the smart city software projects and the [EUP14] list of most promising smart cities. Just as a statistic value we can calculate real energetic cost per citizen of smart services offered from smart cities data centres. From this value we can verify future improvements and study how this specific energy becomes higher while smart services and its effective use increases. We can’t take into account this value until most of services offered became smart ones because energy metrics won’t be realistic (like this use case instance), but in a test way may be helpful.

Table 3: Ratio Barcelona city population/kWh Consumed by Smart Data Centres - 2013

<table>
<thead>
<tr>
<th>Month</th>
<th>Citizens</th>
<th>kWh</th>
<th>Ratio (kWh/citizen)</th>
<th>Cost (€/citizen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.620.943</td>
<td>81.680</td>
<td>19.85</td>
<td>2.78</td>
</tr>
<tr>
<td>2</td>
<td>1.619.943</td>
<td>82.600</td>
<td>19.61</td>
<td>2.75</td>
</tr>
<tr>
<td>3</td>
<td>1.618.943</td>
<td>77.550</td>
<td>20.88</td>
<td>2.92</td>
</tr>
<tr>
<td>4</td>
<td>1.617.943</td>
<td>88.600</td>
<td>18.26</td>
<td>2.56</td>
</tr>
<tr>
<td>5</td>
<td>1.616.943</td>
<td>84.910</td>
<td>19.04</td>
<td>2.67</td>
</tr>
<tr>
<td>6</td>
<td>1.616.943</td>
<td>89.900</td>
<td>17.99</td>
<td>2.52</td>
</tr>
<tr>
<td>7</td>
<td>1.615.943</td>
<td>89.650</td>
<td>18.03</td>
<td>2.52</td>
</tr>
<tr>
<td>8</td>
<td>1.615.943</td>
<td>93.850</td>
<td>17.22</td>
<td>2.41</td>
</tr>
<tr>
<td>9</td>
<td>1.614.943</td>
<td>86.400</td>
<td>18.69</td>
<td>2.62</td>
</tr>
<tr>
<td>10</td>
<td>1.613.943</td>
<td>87.600</td>
<td>18.42</td>
<td>2.58</td>
</tr>
<tr>
<td>11</td>
<td>1.612.943</td>
<td>87.100</td>
<td>18.52</td>
<td>2.59</td>
</tr>
<tr>
<td>12</td>
<td>1.611.922</td>
<td>87.200</td>
<td>18.49</td>
<td>2.59</td>
</tr>
<tr>
<td>Average</td>
<td>1.616.441</td>
<td>86.420</td>
<td>18.75</td>
<td>2.63</td>
</tr>
</tbody>
</table>

The table above exemplarily shows energy used by the main Barcelona public data centre during 2013 and Barcelona citizens’ quantity and extracts energy and costs. Up to date, no smart services are being offered from IMI Data Centre, and all minor services are offered from private data centres. This reality is supposed to change in a near future, where smart services offered to Barcelona Citizens from IMI Data Centre will increase its percentage. So at the moment this table represents the public spending both in financial and energy terms on IT services per citizen of a city that aims at becoming smart and is one of the most promising target customers of DC4Cities. Both the cost and the energy data are therefore not adequate to construct a market volume for DC4Cities – however, projected with the number of citizens in the top ten cities they can give an idea about the magnitude of the target.
III. IDEAL CONTEXT FOR DC4CITIES POTENTIAL

Having established some introductory facts about the current context for DC4Cities in Europe it is understood that under these conditions the market potential for DC4Cities is limited. However, as explained, DC4Cities is a visionary project the origin of which was oriented at the EU’s ambitious expansion goal for the share of renewable energy sources. Therefore, as explained in the introduction, the real potential of DC4Cities lies in the future, assuming the political, economic and technical framework follows the road taken during the last years.

Consequently, in this chapter the market for DC4Cities is analysed not under the current, but under favourable conditions. As DC4Cities is aimed at DCs within the smart cities context, this context needs to be defined, especially with regards to energy issues and the status of the smart city implementation. Additionally, in order to estimate the DC4Cities potential, likely candidates on the part of data centres need to be identified.

III.1. Energy Market in Smart Cities

III.1.1. Market Actors

III.1.1.a. Aggregators

Consumer access to energy markets is a barrier for the development of demand-side management. An aggregator is an entity that clusters small-medium consumers and/or producers, and operates in the wholesale and/or retail markets, as these are not in practice available to small producers/consumers.

Three different types of aggregators can be defined:

- Generation aggregators cluster a group of electricity producers, generally distributed generators. Small producers usually are not able to trade in the electricity market. Thus, they require the services of an aggregator to be able to participate. They may offer dispersed and atomized generation in the market. Moreover, as they play in the market as a single unit, aggregators can more easily manage deviations coming from local renewable producers. At present, the generation aggregator already participates in most electricity markets; in some countries like in Spain it is even obligatory for a renewable plant to contract the services of an aggregator if the plant is going to sell energy in the wholesale market. A retailer can also offer these services, if it has the appropriate license.

- Demand aggregators represent a group of consumers (residential, industrial or tertiary) in the market. They can provide different services, the main one being the achievement of more competitive prices due to the possibility for consumers of participating indirectly in the market and the achievement of more flat energy profiles while consumptions of different type are aggregated. Furthermore, they can manage consumptions in case of demand response. In this case, it would be also not possible for small consumers to trade in the electricity market without this actor. Their main function will be to gather the flexibility of consumers to offer demand response services. At present, in most of the countries in Europe, there are not many load aggregators that represent small or medium consumers in the market.

- Mixed aggregators include both consumers and generators.

The role of the aggregator will surely gain importance as electricity grids become smart grids, requiring a more active participation, especially regarding demand side management.
Figure 25 – Bi-directional flow of information demand aggregator

Focusing on the main features that demand aggregators would have in order to foster demand side management and therefore, to create the ideal conditions needed to increase the market opportunities of DC4Cities, the following characteristics can be highlighted:

- **Group consumers – “aggregate”**

  Demand aggregators create a pool of demand-side resources which could be offered in the wholesale or retail market. This could provide access to the market for small or medium consumers through economies of scale, as transaction costs for a single consumer would outcome potential benefits.

- **Manage consumption and revenue for demand-side response**

  Aggregators would allow the demand-side to participate effectively in the electricity market. This would encourage the consumers to change their electricity usage patterns.

  New market structures should be created in order to reward balancing and capacity from demand-side and maximize flexibility. Nowadays, balancing services are provided to the system from the supply-side. One possible alternative could be to design a capacity market in which demand-side capacity can be rewarded. However, as capacity markets are not always suitable depending on the specific market structures and regulations in each country, other market mechanisms could be more appropriate to encourage demand response to participate in providing these services.

  Furthermore, dynamic price signals would have to be visible to the end-use consumers through the aggregator.

  It is important to note that the Energy Efficiency Directive encourages the participation of demand-side in the electricity market, pointing out that Member States shall ensure the removal of those incentives that might hamper participation of demand response, in balancing markets and ancillary services procurement [EED12]

  Moreover, aggregation could achieve lower costs for electricity when compared to individual consumers because of economies of scale and probably more flat consumption profiles, especially when they include different types of consumers such as residential, industrial and tertiary.

- **Balance supply and demand in a cost-efficient way**

  Demand side response can be capable of providing balancing services in some cases at a lower cost than generation side.

  Nowadays, balancing energy is mostly supplied by thermal power plants, which are more flexible and some of them have moreover a short start-up time in comparison to other manageable power technologies. Investments needed for thermal power plants would decrease if other complementary balancing mechanisms also exist. Demand side management has the advantage that it does not need much costly hardware and infrastructure investment.
Therefore, aggregation and demand response would have a positive impact not only in those customers that are able to be flexible, but also for the whole system.

- **Makes bi-directional flows of information**
  
  Aggregators could create a bi-directional flow of information and energy with the national grid (or also at microgrid level), run by the System Operator, and the market. As mentioned before, they could also communicate with consumers and manage their consumption.

  Aggregators will play an important role with the development of smart grids and a growing electricity demand, mainly because of the proliferation of distributed generation and the fact that demand-side regulation can optimize the current infrastructure without increasing the generation capacity.

Demand-side aggregation shows a series of system-wide benefits.

- **RES integration**
  
  Flexibility in the demand side enables consumption to adapt to the grid conditions, including balancing power generation from intermittent RES. This way a higher level of RES penetration can be achieved. Moreover, demand can be shifted to those hours in which a higher share of RES is available.

- **Avoid unnecessary operations of CO₂ intense power plants.**
  
  By achieving a more even demand curve, power plants are expected to work in a more constant manner. An even curve reduces the number of starts and stops required to balance load and generation. As peak generation is generally performed by thermal power plants, cost, fuel consumption and/or CO₂ emissions of electricity would decrease.

- **Shave peak power demands**
  
  Some of the consumptions that take place at times of peak demand could be shifted to other periods of less demand, thus making the demand curve more horizontal and flat. In some cases, investment in peak-generation infrastructure could be postponed or avoided through demand management carried out by aggregators. Nowadays, energy provided in peak hours is mostly supplied also by thermal power plants. Furthermore, the usage of renewable energy can be increased, as a larger profit of renewable resources could be obtained during valley periods (e.g. wind energy during the night). Industrial users can provide certain flexibility in their production, while smaller residential and tertiary consumers can individually shift their demands to globally achieve a more adequate consumption profile.

Individual consumers will provide their aggregator information on the consumption they are willing or able to shift. Consumption for appliances such as for example heating and cooling, washing and electric vehicle charging is likely to be, at least partially, put off until hours of lower demand in exchange for a suitable economic compensation. Each consumer can establish its level of flexibility according to individual needs or preferences.

The following charts show an example of how demand response managed by an aggregator can contribute to peak-shaving. Flexible consumers represented by an aggregator can shift some of their consumption in order to reduce peak power consumption. The aggregator collects rewards for consumption flexibility in the market, and provides consumers incentives to provide said flexibility.
This example shows a reduction in approximately 1 MW in peak power demand, equivalent to a 20% reduction compared to expected consumption plant without demand response.

By reducing peak power demand, congestion in transmission and distribution grids could be diminished and therefore new investments in transmission and distribution infrastructure could be in some cases avoided.

These features of demand aggregation match very well with the goals of DC4Cities. In the ideal market situation for DC4Cities, legislation should foster a strong position of a demand side aggregator (e.g. by allowing dynamic electricity prices, so-called real time pricing (RTP)). In D2.1 the Smart City’s Energy Management Authority (EMA-SC) was matched with the SGAM model as “balancing network”. One role or function within the balancing network is the demand side aggregation. This is the role that EMA-SC is focusing on, offering aggregator services to producers and consumers (denominated as mix aggregator).

EMA-SC will request local renewable producers (DER RES) and central grid their current and forecasted energy mix and will determine the global availability of renewable energy for the consumers of the smart grid. EMA-SC will be also responsible for the operation of the microgrid, thus it will manage the DER RES sources within the smart city (the balancing function of the balancing network).

Moreover, EMA-SC will receive current and forecasted demand profiles from consumers. Optimized energy budgets or plans for each consumer will be determined by the EMA-SC, submitting to each consumer their demand profile, which will allow to maximize the usage of renewables and therefore, to accomplish the expected operating program of the different power plants.

As Figure 25 shows, information flows are bi-directional. On the one hand, consumers and generators submit their forecasts to EMA-SC and, on the other hand, EMA-SC provides them both the supply plan and the demand power plan.

EMA-SC is providing demand aggregator services within the smart grid, since consumptions of different type of consumers (residential and tertiary buildings, data centres, etc) are aggregated. On the one hand, flexibilities can be managed taking into account the different characteristics of each consumer and, on the other hand, this global approach allows to obtain all the energetic and economic benefits explained previously, as integrating renewable energies within Smart Cities, balance supply and demand in a cost-efficient way and shave peak power demands.

EMA-SC and consumers will have a contractual agreement, in which the rewards that incentivize demand response mechanisms will have to be defined.
III.1.1.b. Energy Services Companies (ESCOs)

The promotion of an energy services market is also needed for the encouragement of energy management in end-users. The Energy Efficiency Directive also highlights the key role that energy services will play in order to achieve the European energy services and establishes that the State Members shall support this market.

Energy Services Companies (ESCOs) [MRE01] provide energy efficiency services in users/clients’ facilities, which are actions aimed at optimizing the quality and reducing the cost of energy supplies through material investments – such as climate control machinery and physical upgrades in buildings, or immaterial – such as energy management systems. ESCOs generally share economic risk and profitability with their client. Rewards for the ESCO are directly linked to energy savings.

Actions plans for energy efficiency include actions of any type that contribute to a higher level of energy efficiency and a reduction in energy expenses.

Regarding data centres, ESCO could optimize the use of renewable energies and energy efficiency installing new equipment, as highly efficient chillers or energy storage, but also improving energy management and implementing flexibility mechanisms. Therefore, an ESCO could be the responsible for implementing DC4Cities in a data centre.
There are several formulae that can be used for the contracts, each of them sharing risk and profitability in a different manner. The most suitable contract depends on the action plans carried out. As explained in deliverable D2.1., the most suitable contract in the context of DC4Cities will be the Energy Performance Contracts (EPCs). EPCs are common when a broad set of energy efficiency actions are performed, affecting electricity, fuels and/or water supply. In these kinds of contract, the ESCO guarantees the efficiency and therefore, the energy savings, of the systems modified/installed through the action plans.

In order to determine the savings, yearly adjustments must be made in order to calculate the baseline to which the measured energy is compared. Said adjustments can include changes in energy pricing, climate conditions in that specific year and variations in usage levels such as occupation or thermostat temperature. This way, the baseline consumption can be projected, providing an accurate estimation on the consumptions that would have taken place excluding the effects of the action plans. The avoided costs, or savings, are calculated as the difference between adjusted baseline and measured consumptions.

Rewards perceived by the ESCO are directly linked to energy savings. Therefore, it is crucial to establish a precise measurement and verification plan in order to correctly quantify energy savings. After the end of the contract period, the client remains owner of any equipment installed. No further payments to the ESCO are made. However, the client will be from there on in charge of O&M duties previously performed by the ESCO (or a third party subcontracted by it).

This type of contract could also apply to a guarantee of usage of renewables in the client, instead of guarantying energy savings. In this case, the ESCO will be responsible for installing a new local power plant and will manage the productions and consumptions in order to optimize the energetic behaviour.

As has been mentioned before, using an ESCO has several advantages:

- **Technical expertise**
  First of all, clients’ can benefit from ESCOs technical knowledge. Their expertise enables them to analyse all savings opportunities, thus maximizing efficiency gains. Furthermore, ESCOs are capable of designing action plans which include a broad set of technical solutions, including non-conventional technologies such as RES.

- **Shared goal**
  As the ESCO’s rewards ultimately depend on the increase in efficiency, both ESCOs and clients will share the common goal of maximizing energy efficiency or other defined KPI until further measures are no longer profitable. This ensures a win-win situation for both parties assuming economic risks and rewards are fairly distributed.
Action plans designed by ESCOs may include the use of RES when economically viable and technically possible; as their service’s goal is to reduce their clients’ energy costs by choosing the best alternative from the available technologies.

- **Energy management**
  ESCO companies normally use Energy Management Systems, being capable to have a better control of the energy usage and improve the operation and efficiency of the customer energy system.

- **Single interlocutor – offers guaranteed turnkey solutions**
  ESCOs provide turnkey technical solutions to their clients, as they act as the single interlocutor between them and all equipment/services providers. This enables non-energy-related business and home users to improve energy efficiency through the hiring of an ESCO. Furthermore, ESCOs guarantee their clients the profitability of the contract, while all external suppliers would only answer for their equipment/service performance or quality.

![Figure 29 – ESCo project model [MRE01]](image)

ESCOs are expected to contact utilities in order to obtain energy supplies at the lowest possible cost. Also, ESCOs themselves are likely to provide consulting and engineering services, and provide O&M for the duration of the contract.

- **Provide financial resources**
  In many cases the ESCO will finance the project as part of the contract. The ESCO is rewarded for its investment depending on the type of contract.

  In the context of DC4Cities, the ESCO will act as the Data Centre’s energy manager at facility level, by acting on cooling, lighting and other auxiliary services in order to fulfil energy requirements or goals, as for example to achieve a minimum percentage of energy savings in comparison to a baseline scenario or to ensure a minimum share of renewable energy usage at DC level. IT consumption could be managed either by the DC itself or by an ESCO company, as IT energy management does not necessarily fall inside the ESCO’s area of expertise.

  The ESCO will run the Data Centre’s EMS, thus acting on efficiency or other energetic or environmental improvements from a continuous improvement approach. It will periodically audit, review performances, propose and analyse improvements that affect overall energy efficiency, renewable energies usage and savings. As has been mentioned, ESCOs can also finance investments needed to achieve the goals accorded by contract and the rewards during the contract will be linked to the achievement of these goals.
III.1.2. Market Structure for Dynamic Pricing

Dynamic energy pricing is one of the main requirements for the viability of demand response. Dynamic pricing provides variable electricity prices for end-users. Prices are expected to vary in small time intervals (e.g.: hourly prices). Through dynamic energy pricing, energy retailers bring market conditions (i.e.: pool) to consumers, thus furthering their ability to indirectly participate in the wholesale market. Dynamic prices are not yet a reality in all European countries, especially to small/medium consumers.

As in the wholesale market, dynamic retail energy prices are expected to be strongly dependent on the relation between production technologies availability and electricity demand. At times of peak demand, prices are expected to be higher, since the most expensive technologies are needed to cover a percentage of the demand (e.g. combined cycles, coal thermal power plants). Besides, in the wholesale market, the availability of RES such as wind or photovoltaic can also contribute to set the price. At low demand hours prices will be lowest, being one of the main factors why RES sources cover a higher percentage of demand. Thus, the usage of more expensive technologies and, therefore, the marginal price in the wholesale market decreases.

Dynamic energy pricing can contribute to peak-shaving, as demand is considered elastic: consumers will try to shift their consumption to cheaper periods. Thus, dynamic pricing can contribute to RES penetration. Flexible consumers can adapt their consumption to RES availability if price signals encourage so (cheaper prices at times of higher RES availability).

It is important to note that other additional costs, which have an impact in the total price of the electricity, as for example transmission and distribution charged variable fees, will have to reflect dynamic prices.

Figure 30 – Possible example of cost structure throughout a day in the Spanish grid

In order to develop dynamic pricing systems, the infrastructure and technology needed to enable communication must be available. Advanced Metering Infrastructure (AMI), including Smart Meters, is crucial for two-way communication with the grid.

A liberalised market where consumers and retailers are able to negotiate and in which consumers can choose between a variety of suppliers encourages competition and therefore pricing that better reflects the reality of system costs.

DC4Cities’ economic viability partly relies on cheaper pricing at times of higher RES availability. Therefore, the optimal market for DC4Cities is one where RES availability is paired with lower prices. It is important to note that additional incentives by the regulators to
reward energy usage and the accomplishment of the Smart City policies can be a complement to the prices signals from the market.

![Hourly Price](image)

**Figure 31 – Energy daily wholesale market prices throughout a day in the Iberian market**

In order to judge what dynamic pricing can mean for the DC4Cities framework, the following settings need to be distinguished:

- In the case that the energy supply from the DC can be considered the same as the national grid, a perfect energy market with real time pricing (RTP) in the range of 15 minutes or the time interval used by the wholesale market to set electricity prices, where renewable energies, CO$_2$ and/or other environmental costs are the main factors to set the electricity prices would imply that DCs can act solely rationally. In this case the DC4Cities framework is needed only to a very limited extent because the orchestration that EMA-DC is doing (supported by RenEnergy contracts) can be mainly replaced by the orchestration through a perfect market, as the more advantageous energy prices will be linked to higher percentages of renewable energies in the generation mix. It means that DCs would plan their workload as well as HVAC or energy storage decisions based on the (forecasted) market prices, and electricity from renewable resources would be consumed to a degree determined by the market conditions, since the optimization of the energy expenses would maximize the usage of renewable without being usually needed additional rewards.

- In the case that the renewable optimization should be done at microgrid level, additional mechanisms could be needed. The dynamic prices relate to a whole country (or the nation-wide smart grid at distribution level) and thus are determined by a country-wide average supply of renewably based electricity. However, in the local (micro-) grid the supply with renewable energy sources can differ from those aggregated values. In this case a smart city that has the goal of increasing the share of renewable energy might cooperate with local RES providers and support DCs in their smart city to lower their energy bill by using as much RES as possible because their marginal power cost is close to zero. Here EMA-SC would act as a mediator (and possibly aggregator) between the smart city power consumers (among them DCs) and the power retailer. The DC would profit by signing RenEnergy contracts because overall this would decrease their electricity bills. In this case the whole scope of DC4Cities would be needed.

- An energy market with dynamic prices, but the CO$_2$ and other environmental factors (% RES, etc) costs are not fully integrated and thus "external cost" from the point of view of the DC: If the smart city’s renewable energy goals are higher than market based result would be it could either issue strict municipal by-laws or attractive RenContracts
with DCs and other commercial energy consumers. In case the Smart City has no budget to finance this increase of renewable based energy sources the incentive structure of the RenEnergy contracts would probably focus on penalties. This is a possible but unlikely scenario: Unless all cities in Europe behaved in the same way, the smart city would risk private DCs to re-locate outside the smart city. In case the Smart City has a budget to increase the share of renewable energy sources the focus of the RenEnergy contracts could be on the reward side and thus relieve the energy budget of a data centre to a certain degree so that its competitive position might be improved rather than worsened.

In all these cases (apart from the perfect market described in the first bullet) the RenEnergy contract has the function of correcting the market distortions originating in the in-perfectness of the energy market. In Europe of today, retail electricity prices are dynamic only to a very limited extent – but also envisioning the future of the energy market in some decades, where dynamic prices will be a fact, a perfect market is highly unlikely. For DC4Cities this means, that to increase the share of renewable energy in smart cities, the full scope of the framework is needed also in an idealized future.

### III.1.3. Technology as a Business Enabler

In order to achieve a broad development of smart grids, technological changes in the different layers of the grid are required. At high level, three main layers can be distinguished:

- **Power layer:** power generation, centralised or distributed.
- **Infrastructure layer:** transmission and distribution grid, metering, communication and protocols supporting IT infrastructure.
- **Application layer:** functionality that extracts information from the end-user to provide energy information to the grid.

![Smart Grid](image)

**Figure 32 – Smart Grid [SMG01]**

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15 The prices between RES based and fossil based electricity prices are distorted and therefore the cost of RES electricity is still comparably high.

16 E.G. due to a subsidy from national or EU plans
At power layer, one of the main key enablers to achieve a broad usage of intermittent renewable sources (e.g. wind and solar energy) will be the deployment of energy storage technologies, not only in the supply-side but also in the demand-side (installed in the end-user).

At infrastructure layer, the deployment of smart meters that can measure energy production and consumption and provide information to the system in real time is required.

End-users or energy services providers will require energy management systems that will acquire actual data from both, electricity grid, and will perform management and control to optimize the energy consumption.

The aforementioned technological resources are fundamental for the development of a Smart Grid. Energy storage technologies enable a higher penetration of RES. They also contribute to Demand Response, by empowering end-users to shift their purchases from the grid.

Smart meters allow for detailed, two-way information exchange between the different parties: distribution grid, distributed generation and the different types of consumers.

The management and exploitation of said information can be carried out by a central Energy Management System, which can be operated by the EMA-SC. However, further information and energy exchanges can exist between parties.

III.1.3.a. Energy Storage

Energy storage technologies [AEE12] are expected to play a major role in the power system. Mature energy storage technologies already exist, such as pumped storage schemes, but other technologies such as large-scale batteries are still being developed. Energy storage technologies have a special relation with RES, as these are often non-manageable. By installing significant amounts of storage capacity, the viability and competitiveness of electricity from RES could be improved.

First of all, the manageableability of electricity from RES would enable an increase in intermittent RES installed capacity, such as wind or photovoltaic. The ability to dispatch electricity from renewable sources would make these more competitive, thus increasing market competition and liquidity.

Furthermore, production could this way be adjusted to forecasts, providing a more reliable system.

By managing energy delivery to the grid, the construction wind or PV plants in some isolated locations with high generation potential could become viable: decreasing peak power supply to the grid reduces the necessary investment in transmission infrastructure.

Storage facilities can eliminate fluctuation of active power caused by the instability of some generating systems. They can also control active and reactive power in order to regulate tension in distribution networks.

In case of power loss, storage infrastructure can act as an emergency power source, and may act as Uninterrupted Power Systems (UPS) for critical applications. Thus, energy storage can increase supply security.

Also, energy storage facilities can guarantee power availability in peak demand hours.

The existence of storage capacity makes it possible for generating infrastructure to be used in a more efficient manner, e.g.: reducing the number of starts and stops and therefore increasing overall energy efficiency.

Investments in transport and distribution infrastructure may be differed, as energy storage in both generation and consumers’ ends tend to even out the daily load profiles.
Energy end-users would also benefit from distributed storage infrastructure. A consumer with storage capacity can profit from lowest prices during off-peak hours by buying cheap energy from the grid. The consumer can later use this energy in more expensive hours, or even sell it back to the grid, becoming a prosumer. Energy Management Systems are necessary for efficient demand management. Consumers can store energy at times of high RES availability, and use this energy when less renewable energy is available in the grid. Furthermore, consumers can use their storage capacity in order to provide flexibility for peak-shaving demand response.

In the context of DC4Cities, end-users can use energy storage in order to adapt their consumption to RES availability. Thus energy storage within the DC is the complementing hardware technology to DC4Cities that makes it easier for DCs to adapt to RES availability. However, in order to be valuable in the DC4Cities context, the technology needs to get less costly.

There are various electric energy storage technologies, the most widespread and mature of which is pumped storage. It basically consists in reversing a hydroelectric turbine in order to store the energy consumed by the pump-turbine in the form of water stored in a dam (gravitational potential energy).

Mechanical flywheels store energy in the form of kinetic energy by using a motor to provide speed to the flywheel. These systems have a small response rate but a relatively low energy density. Also, the stand-by energy losses can reach 20% per hour.

A large variety of electrical batteries are currently being studied for large-scale applications. These technologies are at the moment in different stages of maturity, and show different strengths and weaknesses.

The strengths and weaknesses of each technology determine their suitability to each application. Therefore, the coexistence and competition of several technologies is to be expected in the future.

Nominal power is one of the key characteristics of storage technologies. It determines the magnitude of the services it can provide. Some kinds of low-power batteries are mature as of today, such as Li-Ion portable batteries found in electronic devices. Flywheels and super capacitors exist in the market and are reasonable mature. These offer nominal power ranging from a few kW to a few MW. High-power energy storage (measured in GW) is achieved through Pumped Hydro Storage (completely mature) and diabatic Compressed Air Energy Storage (maturing).

Currently developed technologies include large batteries, such as Li-Ion stationary batteries and flow batteries.

Technologies in development include hydrogen fuel cells, adiabatic CAES, Superconducting Magnetic Energy Storage (SMES) and Synthetic Natural Gas (SNG).

Another important parameter in technology choice for a specific service is response time, which is the time needed to take a storing device from stand-by to full functioning. As a rule of thumb, greater nominal power implies greater response time.
III.1.3.b. Smart metering

Smart Meters are devices that record consumption in short time intervals, and communicates data frequently. Smart meters enable two-way communication between user and retailer/central managing authority. They must also be able to display information to the user. Smart meters provide energy retailers and end-users detailed information on consumption. Energy retailers gain access to consumption profiles instead of periodic interval measures. This data enables retailers to better predict future consumption for every individual, thus reducing the need for balancing services and increasing efficiency.

Smart meters also make variable pricing possible. This way, variations in wholesale market prices will be passed on to the consumer. Dynamic price signals encourage demand response, which in turn increases overall efficiency of the system. Smart meters provide end-users data on their energy consumption. While smart metering on its own does not provide energetic or economic savings, energy-awareness in consumers, together with variable pricing signals and energy management systems, encourages users to shift demand from peak hours to other cheaper period as a kind of demand response and also to improve the
efficiency. Therefore, smart meters play a key role in the development of demand-side response (DSR).

Whenever an energy end-user owns or operates generation, it can be considered a prosumer. Prosumers can use their generation assets for self-consumption or export to the grid. In a future scenario, it is expected that they even take advantage of variable pricing by storing energy generated or purchased, nevertheless regulations changes are needed in almost all the countries in order to allow to use energy storage for exporting energy to the grid.

Power meters are the nexus that communicates end-users with the grid. They display real-time production/consumption, and other grid conditions such as RES availability and price. Therefore Smart Meters are vital for the development of a Smart Grid.

III.1.3.c. Energy management systems

An Energy Management System (EMS) is a system aimed at monitoring, controlling and optimizing energy consumption. It uses computer-aided tools to precisely manage the energy consumption of the different energy consumers inside an organization, such as lighting, heating/cooling and production machinery. It consists of meters which discriminate consumption for different functionalities, data analysis and storage components and a user interface. It is a centralized system that manages all energy consumption. In a smart city, DCs are only one party of energy consumers, there are others like private companies, stores, private homes etc. The impact of energy resource management on the smart city’s supply with renewable energy sources is the highest if all other components of energy demand are also part of the scheme and managed by an EMS.

![Figure 36 – EMS information flow](image)

Energy Management Systems measure consumption (and behind-the-meter generation, including energy from renewable sources) in a detailed way, and store it in a historic registry in order to characterize energy usage. Said data can be analysed in order to identify potential savings in energy usage or to implement other optimization strategies, as increasing the usage of renewable or minimizing the energy expenses. Therefore, the EMS is an essential tool in decision-making regarding energy usage. EMSs allow energy management by the client (e.g. DCs), an ESCO or even an EMA-SC. In fact, DC4Cities product can be considered as an EMS that can be operated by the DC itself or by an energy services provider (ESCO). Besides, EMA-SC will need an EMS to orchestrate and optimize renewable energy production and DCs consumption in the Smart City.

An Energy Management System can integrate smart meters in order to receive information on energy supply conditions. By using this information, the system can adapt consumption and behind-the-meter generation to grid conditions, thus helping the end-user become a demand-side resource.

Moreover, the full potential of Smart Meters can be achieved in combination with a central EMS that controls a group of entities. As mentioned before, considering DC4Cities context, through an EMS the EMA-SC can control a large number of consumers, including DCs,
schools, office buildings and other public consumers, thus enabling better coordination between their actions. This way, a more efficient energy usage can be achieved.

An EMS run by EMA-SC receives real-time input on local RES availability and national/regional grid conditions from utilities, as well as forecasts from the same sources. It also receives detailed load information instead of aggregated power consumption. This way, the energy manager can make decisions based on detailed information.

Energy Management Systems analyse grid conditions (or other energy sources, as local renewable plants) and consumption in real time.

The adoption of an EMS provides a series of benefits to the user:

- **Identifies energy savings opportunities**
  Precise, real-time data on consumption disaggregated by use can point out energy savings opportunities.

- **Optimizes consumption schedule**
  Energy Management Systems are capable of scheduling consumption, thus benefiting from peak-shaving opportunities. Consequently, the achieved load factor can help the consumer achieve better pricing through retail and improving the environmental behaviour (CO$_2$ emission, RES usage). However, EMS also process data in real time, in order to overcome errors in prediction.

- **Receives real-time data from grid**
  If the EMS includes a Smart Meter, real-time data on grid conditions can be taken into account for more informed decision-making. Dynamic price signals encourage consumers to modify their consumption habits in order to achieve economic savings. For example, depending on grid conditions, it might be more efficient to purchase all energy from the grid instead of using internal generation.

- **Continuous improvement approach**
  Once put into place, an EMS enables the consumer to analyse savings opportunities. EMSs are based on a continuous improvement approach, both from a technical and managerial point of view. When the first action plans have been executed, results are checked and contrasted with the expected result, in order to verify savings. Further savings opportunities can be identified by analysing consumption data.

![Figure 37 – EMS continuous improvement cycle](image-url)
- No need for energy audits

The setup of an Energy Management System eliminates the need for energy audits, as it acts as a permanent auditor.

### III.1.3.d. Smart City Infrastructure

The city infrastructure is formed by the basic infrastructures of transport, energy, water, waste processing organization, telecommunications, etc. The fact of being able to connect all the services of the city allows us to relate across all data which gives them even more value.

![Schema about the interrelations among the city services](ics01)

The full vision that needs this platform will have to allow to be able to get connected all the city services, to be public or private. Therefore, it is recommended to implement a platform in an open environment, interoperable and scalable, providing public interfaces.

#### III.1.3.d.1. Data Collection

The first step within the common infrastructure, is to create a network of sensors that allows to identify and measure the activities that are carried out inside "Smart Cities". The sensorisation is the transformation of physical events registered by devices in data in order to be processed and the objective of this sensorisation is the measurement of observations of reality. In turn, these data are converted into information that can be easily understandable for the end user. Using this information as raw material can be proposed solutions and intelligent services for the area of the city with a strong orientation toward improving the sustainability of the ecosystem.

Reducing the manufacturing costs and extending the useful life of the sensor are the main lines of evolution of this sector. One of the trends in the sensorisation and treatment of data, is to first store gross information of observation (without any type of process) and only later apply the rules of ratification and transformation of the information relative to the observed phenomenon.
Mobile terminals are a class of devices of special interest to the model of Smart City. Its widespread presence in the city gives it the ability to generate large volumes of data that, once aggregated and processed, they can provide invaluable information, in real time, of the situation of the city. Smartphones equipped with cameras or positioning capability, for example, are able to transmit, through wireless communications networks, information useful for city services platform to make decisions in order to optimise services such as mobility, public lighting, or even the distribution of safety or health care personnel.

The communications networks of the Smart City networks allow the interconnection of all systems that compose it, and specifically to facilitate the collection of data by means of sensors, for further treatment and decision making. The communications of the city’s infrastructure includes both fixed networks and mobile broadband networks. Mobile or wireless networks have special importance in the Smart City, allowing the connection of vehicles, mobile devices and people, and very prominently from smartphones that, as noted above, are called to become the sensor par excellence of the Smart City.
The M2M technologies (machine to machine) are a generic concept that refers to the information exchange in data format between two remote machines. These technologies acquire big importance in Smart City, allowing integration into the platform for devices that are connected to it through M2M gateways or through direct interconnection with other devices [MTM11].

III.1.3.d.2. The Smart City IT Framework

Thus, for example, it is possible to reduce the intensity of public lighting in certain areas, and increase it in others, depending on the distribution of the population in every moment; it is possible to alter the programming of the systems of management of the traffic of vehicles and the traffic lights so that the density of traffic is reduced in a congestion zone; it is possible to modify the state buildings air conditioning according to its occupation and the distribution of the persons in its interior; it is possible to guide persons with disability so that in its displacement for the city they avoid areas of difficult access for works, for pedestrians' density or for any another reason.

Once the city becomes in a system that is known and characterized itself, provided with the sensors required for this and the communication networks for which the precise information flows until the processing centres and management, the possibilities for improving the quality of public services and efficiency in its provision are virtually unlimited.

![Figure 41 - IT systems evolution through the Smart City infrastructure](ISE01)

III.1.4. The ideal Smart City Policies

III.1.4.a. Service Policy (SLAs in case of public DC)

The services offered by the public DC will need also to adapt to the new scenario of preferential use of renewable energies. Currently, the public DC tend to provide availability of its solutions and applications in a 24x7 scenario, often without a commitment established in writing. Instead, the new services are provided in an environment of absolute availability at any time online.

With the new scenario that is being designed, in which the exploitation of renewable energies must be possible, it is necessary to reorder these services and create a catalogue of services where each service is placed according to needs, commitments and availability. This should
modify the services or the IT infrastructure, and it might be necessary to relocate the services and do not mix it in any infrastructure as it happens today.

This new catalogue will surely be easier with new services that incorporate than the current ones, but will need to make this effort on both sides. It is clear that not all the services need to be available 24x7 and that an agreement must be reached so that all services that are not essential in a 24x7 service scenario would be available a long period (10 hours?) during daytime hours, and could be activated and visible the rest of the day depending on whether the power supply is renewable or not. This new scenario will require a new effort: publish the availability of applications and solutions in a simple and accessible way. There might be for instance a web portal where the availability of intermittent energy resources is represented by a traffic light in green, yellow or red.

At first, the list of services that are now provided with 24x7 availability and might be candidates to have a different configuration depending on the renewable energy supply is the following:

- Taxes payment
- Request and emission of certificates
- Management of the folder of the citizen (personal details, bank direct debiting's, alerts and notices subscriptions, etc.).
- Communication of questions and complaints to the town hall

This new catalogue would involve changing the nature of services, since they should be more flexible in its availability, as we would have services that could be adapted by lowering their criticality or adapting them to a flexible infrastructure. In any case, it would be a change from the current situation of the provision of services by a public DC.

**III.1.4.b. Other DC4Cities Policies**

Other policies not exclusive from public DC can be established and therefore adapted to the new scenario of preferential use of renewable energies. Many aspects of the daily life of the cities can be modified. Some will require a huge and collective effort, but others may be established with a little effort only. Thus, some performances in the scope of public transport, sectors such as tourism or trade, or the inhabitants themselves, can help to improve the life of cities.

The collaboration of different actors will require and find synergies with other entities, both public and private, to achieve the objective of improving life in the cities. All these new policies may require new technologies that nowadays we don't know or are being developed in an experimental phase. Therefore, it is important to create synergies and enable public and private shared operations.

We know that the DC are large consumers of energy in cities, but are not the only ones. Many of the everyday actions of a city's activity can decrease the energy consumption with certain corrective actions. And, where is not possible its significant decrease, this consumption can be reoriented to be carried out in moments of greater distribution of renewable energy. As the processes in a DC can be reoriented, the everyday actions should be scheduled to moments of higher supply of renewable energy.

The recharge of the fixed or mobile mechanisms that operate in the city may be reset. Buildings that have their own autonomous sources of energy in the event of lack of supply can plan recharging their batteries at the time of supply from renewable energy. Electric vehicles of public transport fleets can be programmed for parking and charging at the time. Local waste recycling plants can increase its activity at the moment in which renewable energy is supplied by energy distributors, while at times of low renewable energy can supply other processes of the plant itself which are activated.
All these actions will require creating new routines. If DC4Cities is to be promoted to its full potential not only the City Councils and public institutions should serve as an example demonstrating the use of renewable energies via the implementation for DC4Cities for the public data – being data centres owned by the smart city or in data centres commissioned by the smart city. Thus, the City Government can be the example and the engine of this change. They can guide and create synergies with the private sector to achieve these objectives, creating a cluster of knowledge and sharing interests and goals. They can also guide to create the indicators needed to know the status of the power supply and to provide this information. Finally, the Councils can offer the collaboration with active citizens, individually or collectively through their associations, which would help to share the message with the aim of achieving the desired improvements.

Additionally to that a strong community might issue its own by-laws that state the official goal of an increased renewable resource share and the improved digitalization of the city to ensure a modern life-style. The Amsterdam DC policy about accepting certain DCs only under certain conditions [AMS13] is a first step in this kind of municipal by-laws and worth mentioning. Maybe this goal would be based on a new and strengthened EU technical roadmap compared to the one issued in 2009 [ECS09]. Such a technical roadmap might come with a budget that helps communities to increase their renewable share so that they could dedicate funds to RenEnergy contracts as incentives for collaborating DCs.

**III.1.4.c. Potential Smart Cities**

In section II.3.2 the current potential for marketing DC4Cities in Europe was outlined, based on the [EUP14] study that identifies “smart city candidates" in Europe. It turned out that nowadays, roughly half of the cities over 100,000 inhabitants deem themselves “smart” and are at starting point to become IT based and thus susceptible to implement DC4Cities in the area of public data centres or as a client of commercial data centres that process public data. On the other hand, the technology roadmap for smart cities in 2009 aimed at a number of 25-30 European cities with more than 500,000 inhabitants on the verge of being "low-carbon" until 2020. Envisioning the perfect context for DC4Cities would mean to assume at least all cities over 100,000 inhabitants to become smart until around 2030. This would mean a huge market for DC4Cities, because it could target to support the market of processing the public data of roughly 140 Mio people in Europe and thus nearly 20% of the European population. However, not all cities with more than 100,000 inhabitants might subject themselves to the reign of sun and wind in the way envisioned by DC4Cities. But even instead of 468 cities, only the ones that nowadays are making effort to become smart will be cities with high goals of renewable energy (supported, of course, by a favourable energy market structure as envisioned in III.1. ), the market for public data would still comprise data from more than 90 Mio people.

The extent to which cities will become smart in the next decade (regarding both number of cities and level of smartness) of course depends highly on the political will of the European population expressed in political goals, guidelines, technical roadmaps and legislation.

**III.2. Data Centre View**

**III.2.1. Business Models and SLAs**

Nowadays, as explained in II.2.4, independent of the IT service offered to the final customer, DCs follow several business models that are more or less suitable for DC4Cities. Figure 42 relates typical business models to the dimensions outsourcing factor and SLA flexibility. Ceteris paribus the farther away from the origin a business of a DC is located, the easier it

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17 These figures are based on the excel file that fortunately was provided by the authors of [EUP14]. We are very thankful for these data.
can adjust its power demand profile to the power supply profile of intermittent energy sources like wind and sun as the arrow in Figure 42 shows. This means that DCs, in order to be successful in the DC4Cities scheme, need to become much more flexible not only with regards to their SLA but also with regards to their business model. For instance, as mentioned before, co-location services gives DCs generally less scope to manipulate the power profile of the DC than application hosting or SaaS. So in order to make the DC landscape “fit” for DC4Cities the percentage of SaaS business models in the DC market should increase.

The perfect situation for DC4Cities would be a market that is totally composed of “Everything-as-a-Service” business models with highly flexible GreenSLAs which even allow the halting of services if power supply from RES sources is scarce.

However, this vision does not take into consideration “hard” requirements for IT services which are mission-critical or vital for some parts of the population: there will always be applications where instant reply and powerful computation is undisputable, be it the traffic management in a smart city, some medical simulation for a surgery or an important deadline for a company or mission critical internal applications.

However, there is no way of determining what is “mission-critical” and “vital” and what isn’t but through the pricing of this “immutability”\(^\text{18}\): In the future perfect DC4Cities world, the economic framework should be constructed in a way to make rigid SLAs extremely expensive. Lastly, the price determines what users define as “mission critical” or otherwise untouchable and thus without allowing compromises on SLA (also internal SLA) rigidity.

Regarding applications being mission critical, current definitions state:

“A mission critical system is a system that is essential to the survival of a business or organization. When a mission critical system fails or is interrupted, business operations are significantly impacted.”\(^\text{19}\)

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\(^{18}\) Or through jurisdiction – this, however, would require a level or government ruling that might not be in line with a democratic social-capitalism system.

Activity, device, service, or system whose failure or disruption in normal business hours will result in the failure of business operations. For example, for an online business, the communication system is mission critical; for a steel mill, water and power supply have the same importance.20

Additionally to mission critical applications there are also applications which need extremely rigid SLAs because this SLA is vital for the functionality of the application, like the aforementioned cases of public or medical applications.

So, even if in the perfect DC4Cities world everything is offered “as a service”, there will always be a fraction of SLAs that cannot become green. And it is virtually impossible to determine how big this fraction is and so what would be the share of the data centre business in a couple of decades that is not adjustable at all. According to Horison Information Strategies21 around 15% of company data are mission-critical. When looking into our own research [A4G14], a questionnaire revealed that only one third of DC managers might consider shedding about 20% of load for 2 hours if rewarded adequately – only about 15% would shed 40% (however, this question related to the total power consumption in a DC, i.e. including HVAC). Judging from this reluctance, under the current conditions (e.g. energy prices, energy laws), the potential to shift applications is much lower than just for mission-critical data. For the next phase of DC4Cities it is envisioned to create a service/application catalogue of the trial partners’ DCs and judge, which applications are flexible in order to base the estimations on firmer ground.

The current natural development of business models is heading in the desired direction anyway, as e.g. IDC forecasts for the coming years: It expects global cloud computing to nearly double between 2013 and 2017 [CBR14] – all other studies, also more long term oriented data, point into the same direction. So considering that nowadays the bulk is in colocation, a small chunk in supercomputing (which could also be interpreted as “computation-as-a-service”) and cloud computing on the rise (see Figure 43, [INT14], [A4G14]), the ideal DC4Cities future, where DCs are responsible for the greatest part of the management and value chain of IT service supply does not seem far-fetched. This development is underpinned by surveys like [SAI12] that state that already nowadays one third of mission-critical applications are in the cloud and predict that until 2015 this ratio will change to half-half.

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So, both from a renewable energy and business viability point of view, data centres of the future will most probably become more modular, more dense, more automated, and be building on a “pay as you grow” principle, as e.g., foreseen by Aaron Davis at the TGG 2012 forum [TGG12]. This natural development will prepare perfectly the ground for DC4Cities.

**III.2.2 Legal ownership**

From the point of view of who owns a data centre, it is obvious that publically owned data centres are a much easier “target” for DC4Cities than privately owned data centres. In the DC4Cities vision, the SMA-SC, the service management authority of the smart city is part of the smart city administration and thus shares the same overall goals. As long as these goals include – by the rule of the EU or through its own commitment – an ambitious share of renewable energy resources, these smart city data centres will be the ideal customers for the DC4Cities solution. Running a publically owned data centre with DC4Cities based products can be seen as one implementation of green IT guidelines. That this is not unrealistic becomes obvious looking at advanced guidelines for running public data centres like they are issued already today by the city of Stockholm [STO14] as part of an integrated environmental strategy for 2030. Publically owned data centres in cities with such guidelines will have to adapt their investment and operational business rules to sustainability issues like the ones implemented in DC4Cities.

![Figure 44 – Data Center Energys Metrics [DCE01]](image)

However, also commercial data centres that process public data in commission for the smart city administration are subject to the green IT guidelines of the smart city. This differentiation is important, as not all cities process the public data themselves, partly due to cost-saving outsourcing strategies, partly because they wish to support local data centre industry. Here,
the implementation of DC4Cities based products can be turned into a part of the outsourcing strategy, compelling bidders for the processing to adhere to certain shares of renewable energy sources, expressed in the metric RenPercent. So, wherever public data are being processed, DC4Cities can be implemented more easily than in a private commercial environment.

But also other commercial data centres in a smart future are interested in applying DC4Cities policies and thus are potential customers for a DC4Cities based product portfolio. There is a variety of reasons for that: One is increasing customer awareness for sustainability and energy issues. The beginnings of this changing attitude is revealed already today through a short internet research for green webhosting services\textsuperscript{22}, in monitoring websites for companies like eBay that publish information about their share of renewables (rather low!) and PUE as Figure 44 shows. A summary of this current development can be found in [GRE14] where the energy sources of various data centres and web services are presented.

Nowadays, data centres stating that they are running fully or partly on renewable energy either have some onsite renewable production, REC (renewable certificates) or long term purchasing contract with producers of renewable power. To our knowledge however, none of them adapts their workload and power load to the availability of renewable resources. However, with a changing business and energy environment as projected in the preceding sections, they might adopt new strategies like the ones suggested by DC4Cities and thus become potential customers.

**III.2.2. Service Characteristics and Workload Shape**

As has been extensively described in the previous chapters, ICT technologies are instrumental to the set-up of a Smart City environment and to the deployment and evolution of its services.

The variety of IT services in a Smart City is potentially endless, and this is also due to the potential for cross-fertilization between ICT and Smart Cities: the development of ICT technologies gives rise to new services and new service demands, which in turn spur the development of new technological solutions.

![Figure 45 - ICT-Smart City cross-fertilization](image)

A not exhaustive list of ICT-based services available or implemented in a Smart City includes:

- Energy monitoring and optimization;
- Environment monitoring;
- Waste management;
- Mobility and transport;
- Intelligent lighting;

\textsuperscript{22} A google search for „green webhosting companies“ resulted in more than 57 Mio hits.
- Telework and telecommuting;
- E-health;
- Welfare and social inclusion;
- Education and e-learning;
- E-government;
- Management of cultural heritage;
- Security.

Accordingly, here follows a tentative list of the main actors, and data centre owners/managers in a Smart City:

- City administration;
- Energy utilities;
- Environmental agencies/services;
- Hospitals/Health system;
- Schools/academia/educational system;
- Police/security.

Examining the two lists given above, it can be recognized that the vast majority of data centres involved in a Smart City are characterized by a load factor that depends heavily on time-of-day, day-of-week, and other strong variability. Most services deployed require real-time or near real-time answers, and cannot therefore be shifted in time, and “customers” typically require these services in normal business (or working) hours.

Data centre load characterization was studied, for example, by [LBN10]. A specific metric was devised to take into account the load shape:

\[
\text{Average DLF} = \frac{\text{Average Daily Interval Load}}{\text{Maximum Daily Load}}
\]

This metric refers to energy load, but can be indirectly used as a reference to the workload in a DC. Average DLF has a high percentage (typically around 90% or more) in those data centres with a constant flat load, and exhibits lower values in DCs with a strong correlation with time-of-day or other periodicity. If we analyse the typical Smart City services, we recognize that the data centres involved are of this latter category, i.e. mixed-use DCs. Analysis of the behaviour of these infrastructures has shown that the load shapes are similar to those exhibited by an ordinary commercial building.

![Figure 46 - Mixed-use DC load shape](image)

In this case, therefore, there is a strong correlation of energy consumption, and thus of the workload, with average business working hours. The variation between peak and off-peak values of the energy consumption strongly depends on the characteristics of the equipment...
installed in the specific DC under consideration. As we know, in older equipment the variation in energy consumption between a processing unit under maximum workload and one being left idle is quite small, perhaps around 20-30%. In newer equipment these characteristics were improved.

### III.2.3. Customers/Users

In order to pinpoint the impact of customers/users on the prospects of DC4Cities - and outline the "ideal" customer/user - we first need to describe/distinguish these two different concepts. Basically, an IT service customer is the beneficiary of a contract for products/services offered by a data centre. In contrast, a consumer represents the group of individuals that access, thus consume IT services running in a data centre (= users). As illustrated in Figure 47, customers can be both, the consumers of a service (self-consumption) or represent IT service providers, hence reselling their IT service products (unmodified/modified) to end-consumers, potentially through intermediate customers. For instance, a customer may buy a specific IT service product such as a SaaS-based collaboration tool offered by the data centre and consumes it directly (self-consumption). In contrast, another customer may "buy" VM products (e.g. PaaS product) and run an additional service on top of it (e.g. collaboration tool) which is then consumed by its own end-consumers. Finally, under certain circumstances, the data centre may be both its customer and consumer at the same time (e.g. maintenance services operated by DC owner). More details about DC ownership is presented in section III.2.2.

Having explained the difference between IT customers and IT consumers in general, we now discuss the ideal context of those two groups and describe their impact on DC4Cities as a whole. As weather and environmental conditions are the main factors influencing the availability of RES, it is intuitive to assume that the data centre workload must be adapted in order to follow the RES availability pattern. Flexibility constitutes one of the main drivers in DC4Cities to follow a certain RES availability pattern. Despite flexibility provided by the IT infrastructure (i.e. technical potential, see section III.2.7), flexibility granted by customers and consumers represents a high additional potential on the achievement of DC4Cities’ goal as they govern the DC’s business model.

![Figure 47 - Relationship between IT Services, Customers and Consumers](image)

Each group comes with its own shape of flexibility as presented in Figure 48. The primary flexibility of IT customers is related to prevailing contracts, especially SLAs agreed. In contrast, the primary flexibility concern of IT consumers is related to the generation of workload, thus their workload behaviour. The generated workload of consumers is usually time-dependent and has to be matched with sufficient computing resources. Besides, it is important to note that both shapes of flexibility provided are interconnected, because possible workload generated by IT consumers typically builds on the specifics inside the
contracts negotiated between IT customers and the DC (e.g. IT service characteristics such as computing power provided). Without laying the contractual framework for the IT service, mostly SLAs, the potential workload size, thus behaviour is neither predefined nor protected. Offered contracts and its possible content in terms of SLAs depend largely on the business model provided by the data centre provider (see section III.2.1).

In the ideal case, the contract between IT customers and its DC provider has to be as flexible as possible with respect to the exploitation of workload shifting potential in order to achieve a best-aggregated match with RES availability (assuming that the DC aims to make contracts in a way that the aggregated value is sufficient for RES availability matching). In other words, ideally the IT service should be consumed in parallel to the availability of RES in order to maximise the DC’s RES consumption share and to achieve DC4Cities’ overall goal.

![Figure 48 - Ideal Flexibility Provided by IT Customers and IT Consumers to DC4Cities](image)

One approach to enable ideal contractual flexibility is to relax SLAs. GreenSLAs\textsuperscript{23} build on this idea by enabling specification of SLAs that pass more power, thus decision making to the data centre provider in order to react to certain events such as the availability of RES in the context of DC4Cities. Intuitively, IT customers act rational; hence trying to continuously keep costs low. So it should be a matter of explaining to them the concept of specifically targeting their GreenSLA to their real needs — and in turn be granted fringe benefits by the data centre in order to compensate higher risks (e.g. special tariffs, discounts etc.).

At a higher level (EMA – DC), RenEnergy Contracts presented in D2.1 (see section III.2.9.d) provide an instrument for offering incentives to participating DCs in various ways like price based- and reward based compensation and through a penalty or bidding process. Based on such compensation approaches, the DC gains now the chance to further offer incentives to its customers within a GreenSLA. In the ideal context of DC4Cities, each IT customer would negotiate a contract with its DC based on GreenSLAs that offer sufficient incentives. These contracts, on the one hand, need to express expected workload behaviour for contracted IT services in order to adapt computing resources in times when workload changes (e.g. workload patterns). On the other hand, the GreenSLAs need to be as close as possible (needed) to the availability of RES, ultimately reaching a certain flexibility that is required to contribute to the DC4Cities’ goal. IT customers would compensate their risk taking via special tariffs and discounts (e.g. based on a reward/penalty scheme) while in parallel contributing to decreasing CO\textsubscript{2} emissions and increasing energy-efficiency inside the smart city. However, as already mentioned, IT customers have to take care about higher risks (e.g. emergencies) involved in GreenSLAs, thus the analysis of such trade-off between green awareness and higher risks has to be made. Especially in the case of mission critical IT

services as discussed in section III.2.1, GreenSLAs may be difficult to be implemented as workload shifting flexibility would be likely too small.

The acceptance and wide introduction of flexible SLAs acts only as the basis for workload adaptation and a first step towards goal achievement. The actual workload behaviour largely depends on its users, the IT consumers. Ideally, workload needs to be shifted as needed in order to match RES availability. However, this is not always feasible. Generally, the flexibility of workload generated by IT consumers depends mostly on specific use cases. The more flexible the use cases with respect to time, the better the matching to RES availability. Obviously, this can only be achieved with use cases (= workload patterns) that are not mission critical at all or only at certain times. Therefore, ideally the maximum workload potential of specific IT consumers that is flexible in time has to be determined (analysed) and has to be made flexible using SLA relaxations (e.g. GreenSLAs).

The flexibility of each use case and each customer or consumer depends on a variety of factors, among which habits and general expectations from an “always-online” life-style play nearly an equally important role as the final objectives that consumers pursue with their consumption behaviour. Business consumers may typically be not as flexible as (private) home consumers. In the case of business consumers, specific IT services need to be up and running in order to deal with daily operations of the company, thus service degradation may lead to a severe risk in business operations. In contrast, private consumers may accept service degradation for certain IT services such as e-government services or certain entertainment IT services (e.g. availability only for specific time frames such as evenings where a majority of people return from working). Despite from time frame dependent workload generation, [CUR12] argues that workload behaviour of consumers can be positively influenced by raising their environmental impact awareness, thus their sensitivity to IT service consumption. By establishing an improved information flow back to the consumer, the authors give three pointers of how consumers may positively react. First of all, an improved information flow, thus knowledge about the impact of IT service consumption result in more sharpened decisions (increased ecological awareness) at the consumer side when IT service products are chosen. Second, knowledge of measures (e.g. power measurement to raise energy-awareness) about used IT services may further positively affect the consumption behaviour. Last, business consumers may have to adhere to sustainable IT policies setup by the company, hence giving visibility to sustainability goals.

By transferring aforementioned principles to the context of DC4Cities and by having our focus on the availability of RES, we need to establish an information flow back to customers and consumers of IT services in order to impact the workload behaviour positively. As a result, Table 4 summarizes the findings of how customer/consumer awareness can be ideally increased using three instruments in order to achieve potential workload behaviour changes.

For risk-flexible and risk-inflexible compensation models we assume that compensations (e.g. discount) need to offer sufficient incentives, thus price flexibility in order to achieve workload behaviour changes on the customer/consumer side (i.e. positive reactions). Accordingly, in the context of DC4Cities’ RES goal, an adapted environmental chargeback model for low-risk flexibility gives penalties (increased environmental charges) to IT service consumption in (predictable) time frames in which RES availability is low whereas environmental charges decrease in time frames where RES availability is high. In contrast, service quality flexibility, for instance granted by GreenSLAs, enables certain flexibility that comes with the cost of higher risk-taking and is adapted by offering incentives in terms of special tariffs or discounts to certain times (low/high RES availability). The third compensation model, legislation, cannot be really characterised as one, because it is more an incentive to invest in more efficient IT service consumption. According to this “model”, some environmental impact attribute such as caused CO₂ emissions result in penalties (e.g. due to levies, as it is the case for large energy consumer such as large companies). Lastly, it is important to note that if intermediate customers exist (see Figure 47), the compensations need to be further distributed similarly to the consumer (or end-customer) in order to involve the whole chain that impacts the consumption behaviour of IT services.
Table 4: Raising Awareness of Matching Customer/Consumer Workload with RES Availability

<table>
<thead>
<tr>
<th>Compensation Model</th>
<th>Instrument for Information Flow</th>
<th>Low RES Availability</th>
<th>High RES Availability</th>
<th>Raising Awareness</th>
<th>Costumer/Consumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Inflexibility</td>
<td>Environmental Chargeback Model</td>
<td>Increased environmental costs</td>
<td>Decreased environmental costs</td>
<td>Business</td>
<td>IT policies: Environmental charges part of IT chargeback model (usage related to costs incl. environmental charge). Usage is tracked back to consumer.</td>
</tr>
<tr>
<td></td>
<td>– Environmental charge</td>
<td></td>
<td></td>
<td>Private</td>
<td>Cost instrument may impact consumption behaviour positively</td>
</tr>
<tr>
<td>Risk Flexibility</td>
<td>Green Service Level Agreements</td>
<td>Decreased Quality-of-Service (QoS)</td>
<td>Increased Quality-of-Service (QoS)</td>
<td>Business</td>
<td>Relaxed SLAs: Contract basis for improved information flow about IT resource usage and impact on environmental awareness</td>
</tr>
<tr>
<td>Service Quality</td>
<td>(SLAs) – Reward/Penalty Scheme, Discounts, Special Tariffs</td>
<td></td>
<td></td>
<td>Private</td>
<td>Acceptance of service degradation due to rewards (e.g. discounts, special tariffs)</td>
</tr>
<tr>
<td>Legislation (obligation)</td>
<td>e.g. levy for CO₂ emissions (carbon footprint)</td>
<td>Environmental Charge as levy or CO₂ restrictions depending on RES availability</td>
<td>Business</td>
<td>Business customers are bound to obligations, incentive to raise energy-awareness, e.g. avoid to pay higher levies depending on caused CO₂ emissions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Private</td>
<td>Possible levy savings may positively (have to) change consumption behaviour</td>
</tr>
<tr>
<td>Hybrid approach</td>
<td>Combination</td>
<td></td>
<td></td>
<td>Business</td>
<td>Multi-criteria optimal service consumption</td>
</tr>
<tr>
<td>(Costs + Service Quality + Legislation)</td>
<td></td>
<td></td>
<td></td>
<td>Private</td>
<td>Best option selection</td>
</tr>
</tbody>
</table>

In conclusion, aforementioned compensation models may ideally convince IT customers and consumers in a positive way so that a higher flexibility with respect to workload behaviour is achieved that ideally contributes to DC4Cities’ goal.

III.2.4. Energy supply of DCs

Data centres are more likely to apply for DC4Cities, if they already have some grid integration flexibility mechanisms which allow them to support Demand Response strategies as well as green data centres willing to maximise the usage of renewable energy.
Grid integrated DCs

The wholesale price of electricity becomes high during periods of peak demand. An attractive alternative to utilities paying these high rates on the spot market is paying commercial and industrial consumers to reduce demand. The payment for this “demand response” is based on the reduction in consumption during peak-demand events and can be significant, depending on the local market conditions.

Studies such as [GID01] have been performed in that area. Examples of Demand Response strategies applied in that context by data centres are:

- Server and CRAC units’ shutdown.
- Load Shifting or Queuing IT jobs – Server idling
- Temperature set point adjustment.
- Shutdown and idling of IT storage clusters.
- Cooling relative to IT equipment load reduction
- Load migration between heterogeneous systems.

As an example the vendor Power Assure is providing solutions for data centres to take advantage of global energy markets and to support such demand response strategies.

DC4Cities will offer to those data centres which are already integrated in the grid the possibility to control data centre applications as an extra Demand Response strategy.

Green DCs

Data Centres are pushed to use more renewable energy for their green image, because of the growth of corporate social responsibility programs focusing on carbon neutrality. Data centres can put in place on-site generation but they face the challenge of the space needed to generate locally electricity. For data centres with lack of space for on-site generation they can procure renewable energy from their local supplier but the mix of renewables available varies widely from country-to-country.

Such green data centres are part of the addressable market for DC4Cities, because of the high importance given to their green image which will be further enhanced by means of the DC4Cities service. Ideally, DC4Cities tackles data centres that already have some experience with renewable energy and GreenIT, e.g. because they belong to data centre company with data centre sites in various locations one or more of which has worked with onsite renewable generation or other RES issues.

Example for PV Share

The size as such of a data centre does not make it suitable or not to reach such a goal. It is rather the available surface, for a certain data centre size, for RE generation either of the data centre and/or of the smart city, which must be taken into account.

A data centre of around 1,500 m² consumes an average of nearly 40 MWh/day, or the energy equivalent of nearly 8,000 households. To produce this amount of renewable energy by means of solar energy a big area is needed for the PV panels.

For on-site generation, data centres with a small value for the ratio data centre nominal power over maximum possible RE power on the available rooftop surface are good candidates for DC4Cities. As an example on a rooftop of a DC with a surface of 500m² and a nominal power of 400kW, it is possible to have a PV power of approx. 75kW. This covers only 6.2% from the total electricity production. The PV surface needed in the smart city to achieve a 40% RE usage for such a data centre would be 3333m² with a peak power of
500kW. This means a total surface of 3833m² (61.9m * 61.9m) would be needed only for this data centre to reach a 40% RE usage.

For local supplier RE generation, data centres with a small value for the ratio data centre nominal power over RE power considering smart cities' surface are good candidates. In such conditions the data centres are more likely to have a large % of RE provided by the local utility covering the power needed to cover their demand.

III.2.5. Technical Enablers

The cost to put in place DC4Cities depends on the way the data centre is being monitored. Monitoring and control solutions used today are DCIMs and cloud solutions. Data centres with such technical enablers are more likely to add an extra control solution such as the one of DC4Cities because of the limited extra investment needed therefore.

III.2.5.a. DCIM (Data Centre Infrastructure Management)

Data centres with DCIMs (Data Centre Infrastructure Management) allow to closely monitor and utilise the data centre power infrastructure. According to Wikipedia, “A DCIM is the marriage of information technology and data centre facility management disciplines. It is a is a category of solutions which were created to extend the traditional data centre management function to include all of the physical assets and resources found in the Facilities and IT domains.”

![Growth Rate Of Public Cloud Services](http://dcimcentral.com/vendors/). Gartner predicts DCIMs to quickly become mainstream, growing from 1% penetration of data centres in 2010 to 60% in 2014 [GAN13]. A DCIM does not stop at IT device level but goes to the facilities level. As DC4Cities needs to adapt at data centre level to the availability of renewable energy, data centres with a DCIM are better candidates for the DC4Cities solution.
III.2.5.b. Cloud solutions

Cloud providers and enterprises are expected to grow significantly. According to Gartner [GAN02] the Infrastructure-as-a-Service (IaaS) will achieve a compound annual growth rate (CAGR) of 41.3% through 2016 and the Platform-as-a-Service (PaaS) will achieve a 27.7% CAGR through 2016. The cloud services sub segment of multi-owner DCs is projected to grow in the following way:

![Growth Rate of Public Cloud Services In Multi-Owner DCs](image)

Source: Gartner (February, 2012)

The following list are widely used cloud monitoring solutions: AppDynamics, Aternity, Boundary, CA Nimsoft Monitor, Compuware Gomez, CopperEgg RevealCloud and RevealUptime, Level Platforms Managed Workplace, LogicMonitor, ManageEngine, Monitis, NetEnrich, New Relic, Rackspace Cloud Monitoring, SplunkStorm, Zenoss Cloud Monitoring, Zyrion, Nagios, VMware's Hyperic, Zabbix. To maximize the addressable market by DC4Cities, Energy Aware Software Controllers (EASC) should be made available for these cloud monitoring solutions to allow a fast roll-out of the DC4Cities service. Bill Gates Vision: “Information at your fingertips” 1990

24 https://www.youtube.com/watch?v=jxUPSF2K7Cs
IV. FINAL CONCLUSIONS ABOUT THE DC4CITIES MARKET

IV.1. Today’s DC4Cities Market

Today’s market for a DC4Cities based product portfolio is limited by a discrepancy between the implicit assumptions of DC4Cities and the real political and business framework: Implicitly, DC4Cities assumes that a smart city has the ambitious goal to maximize the share of renewable energy sources at its energy mix and that it needs to join forces with all good citizens inside the smart city in order to achieve this goal. It also implies that to some degree a change of the DC’s behaviour of pays off – either directly through reduced prices or for indirectly for the smart city that therefore has a budget to distribute incentives. However, in most countries nowadays the energy market is structured in a way that the volatility of energy prices is not handed down to the retail market so that renewable energy is NOT less costly than fossil based energy. Even though Europe in 2012 enacted the Energy Directive with ambitious smart meter dissemination goals, renovation obligations for public bodies and the requirement for energy retailers to increase energy efficiency by 1.5% each year, the energy cost in DCs speak a different language so that a business model cannot be easily motivated. As this situation will change in the coming decades the market for DC4Cities will evolve; however for the present and immediate future it is limited to specific cases.

In order to outline today’s market, a favourable geographical and political context needs to be specified. First of all, the differentiation between privately and publically owned DCs is important as it determines the degree to which a smart city can influence the behaviour of the DC without the necessity to have funds for incentives. Additionally to publically owned DCs, also privately owned DCs that are commissioned by the smart city to process the municipal data are subject to any kind of GreenIT guidelines by the smart city (see Section II.2.2.). However, as stated in Section II.3, there is not a great number of cities that can be called smart today: Of the 469 cities with more than 100,000 inhabitants, about the half strives at being smart today. And they do this with mixed efforts: some have just expressed interest of initialized a small number of projects, others have brought a plethora of projects in different areas on the way and issued smart city guidelines or even GreenIT guidelines as for instance the cities Amsterdam and Stockholm. The European study [EUP14] identified 26 cities who give great efforts at becoming smart and focus on the areas “smart government” and “smart environment”. The best target cities to market DC4Cities should be found among these 26 cities that are shown in the table below.

Of these smart cities Helsinki, Berlin, Amsterdam, Paris, Rome, Barcelona, Bologna, London, Manchester are the ones that are also dedicated to an ICT based smart city management and thus in the very near future will be equipped with an IT infrastructure that allows the integration of DC4Cities in a relatively simple way. In order get a Top 10 list the city of Milano should be added which is also among the participants of a project to develop and implement a smart city framework and the “best” city in the next category of [EUP14] smart cities (the first to be level 3). In this context it should be pointed out that in some of the countries that dispose of today’s smartest cities in Europe, the gap between the renewable energy share targets in connection with the EU member states’ individual goals for the Europe 2020 strategy and 2012 reality is rather high, especially in Germany, France, GB, Spain and Belgium, so that smart cities in these countries have yet another motivation to implement DC4Cities strategies – maybe even subsidized by their national governments aiming to increase the overall RES share.

So, to market DC4Cities products that are based on the optimization of renewable energy shares in public data centres, these 10 cities could be the early adopters of this novel
approach. In a second wave, the rest of the 26 top smart cities public administrations could be tackled for a marketing campaign in Europe.

**Table 5: Best Target Cities to Market DC4Cities**

<table>
<thead>
<tr>
<th>Smart City</th>
<th>Inhabitants</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>7.074.265</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Berlin</td>
<td>3.460.725</td>
<td>Germany</td>
</tr>
<tr>
<td>Paris</td>
<td>2.211.297</td>
<td>France</td>
</tr>
<tr>
<td>Vienna</td>
<td>1.714.142</td>
<td>Austria</td>
</tr>
<tr>
<td>Barcelona</td>
<td>1.620.437</td>
<td>Spain</td>
</tr>
<tr>
<td>Cologne</td>
<td>1.007.119</td>
<td>Germany</td>
</tr>
<tr>
<td>Valencia</td>
<td>811.738</td>
<td>Spain</td>
</tr>
<tr>
<td>Athens</td>
<td>789.166</td>
<td>Greece</td>
</tr>
<tr>
<td>Stockholm</td>
<td>789.024</td>
<td>Sweden</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>779.808</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Helsinki</td>
<td>588.549</td>
<td>Finland</td>
</tr>
<tr>
<td>Bremen</td>
<td>547.340</td>
<td>Germany</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>541.989</td>
<td>Denmark</td>
</tr>
<tr>
<td>Den Haag</td>
<td>495.083</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Manchester</td>
<td>430.818</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Bologna</td>
<td>378.701</td>
<td>Italy</td>
</tr>
<tr>
<td>Florence</td>
<td>370.092</td>
<td>Italy</td>
</tr>
<tr>
<td>Bilbao</td>
<td>354.024</td>
<td>Spain</td>
</tr>
<tr>
<td>Ghent</td>
<td>241.708</td>
<td>Belgium</td>
</tr>
<tr>
<td>Tampere</td>
<td>213.217</td>
<td>Finland</td>
</tr>
<tr>
<td>Rome</td>
<td>168.883</td>
<td>Italy</td>
</tr>
<tr>
<td>Brussels</td>
<td>155.526</td>
<td>Belgium</td>
</tr>
<tr>
<td>Târgu Mureș</td>
<td>143.939</td>
<td>Romania</td>
</tr>
<tr>
<td>Oulu</td>
<td>141.671</td>
<td>Finland</td>
</tr>
<tr>
<td>Linköping</td>
<td>139.474</td>
<td>Sweden</td>
</tr>
<tr>
<td>Helsingborg</td>
<td>124.188</td>
<td>Sweden</td>
</tr>
</tbody>
</table>

Interestingly, looking into a map of the European DC industry, there is a huge overlap between the most suitable smart cities in Europe and the regional hot spots for commercial DCs in Europe. For instance, zooming into the central Europe with parts of France, UK, The Netherlands, Germany and Belgium it can be seen, that the major DC markets London, Paris and Amsterdam are also among the Top 10 of the smart cities that are the most suitable for DC4Cities. Also, Berlin, Cologne, Ghent, Brussels and most of the other 26 pioneer smart cities are matured DC markets.
This circumstance will help entering a second market segment: commercial DCs with a high corporate social responsibility. Around the world, more and more stand-alone DCs or in-house DCs of huge supernatural companies open up to sustainability issues like CO2 emissions connected with their activities. This to some degree due to the social responsibility of their owners, but in most cases due to the fact that the society (and thus a majority of customers) becomes more and more energy and climate aware and DCs need to account for this (see II.2.2. ). Above mentioned cities are governed by a public administration whose goals are in-line with this general development – this will no doubt foster the inclination of commercial DCs in these cities (even smaller ones as they get aware of the pioneers like Google or Apple) to be among the first to adopt strategies that help increasing their share of renewable energy sources. These potential customers will go for a different part of the DC4Cities product suite: Only in rare cases dependent on RenEnergy contracts with the smart city, but rather focused on the internal DC energy adaptation strategies.

In these cities, GreenIT policies of the smart city administration might compensate to some degree the European lack of GreenIT legislation and the missing price signals of electricity scarcity in specific periods of time (e.g. low sun irradiation). This slightly positive context of energy aware smart cities, however, is still set off today by the current tendency of companies to outsource their computation needs into co-location DCs with rather inflexible SLAs. As shown in II.2.4. other business models like SaaS or application hosting grant the DCs a higher degree of freedom to schedule processes in accordance with the pattern of sun and wind. However, a general tendency toward cloud computing based business models which are much more suitable for DC4Cities policies is already on the rise, as illustrated in II.2.2.

Another stumbling block for the enactment of power capping or power rationing strategies as suggested in DC4Cities is our current always-on-everything-now way of life. In the past decades, in most European countries we have got used not only to the “information at our fingertips” but also to social contacts and task completion (e.g. online banking) at our fingertips at any time of the day – or the night. This has led to a general expectation that counteracts the DC4Cities strategies in case they have an impact on quality and access of customer services. Just imagine the offerings of eBay or Facebook being downgraded to a lower service portfolio in times where the local energy from sun and wind is low or absent. The consequence of this expectation is that both public DCs (or the smart city administration in collaboration with EMA-SC as client of a private DC) and commercial DCs need to carefully select services where the impact of a decreased service package on the users’ perception is low. It also means that strategies impacting the users’ service experience should always be a last resort.
IV.2. The Potential Market for DC4Cities in the 2030s

The potential market for DC4Cities in the coming decades is marked by a high level of uncertainty because the market size is to a great degree dependent on political and economic developments that we cannot foresee today. However, it is possible to outline which circumstances will increase the chances for DC4Cities to be marketed in Europe and which will be rather limiting factors.

In order to do this we can take two different points of views: The view of the technical and the view of the business potential of the DC4Cities market, a differentiation first found in [FFE10]. The technical potential of a market is characterized by the value of the sum of all imaginable technical applications of a product, whereas the business potential answers to the question if these technical applications are also economically viable for the business actors. The business potential will always be a subset of the technical potential of a market. And the higher the magnitude of the technical potential, the higher the magnitude of the business potential can be – however, to which degree the business potential approximates the technical potential will always depend on the political and economic framework as well as on the general attitudes in the society.

For DC4Cities the technical potential will depend on development of the following trends:

- Smart Cities: the more smart cities there will be in Europe the more public data centres or private data centres processing municipal data will be potentially interested in acquiring DC4Cities based products. As mentioned in II.3, if all cities with more than 100,000 inhabitants became smart in the coming decades, DC4Cities could tackle the public market dealing with municipal data of 140 M people. But not only the number and size (re. e.g. inhabitants, traffic, surface…) of smart cities is relevant, but also the degree to which they are smart and produce “big data” which need to be processed as well as the technology they choose for various issues. For instance, regarding traffic management there might be different options regarding sensor networks, either more focusing on sensors in the infrastructure or on sensors in moving objects – all with different implications for the centralization, characteristics and magnitude of data management. But also, the more smart cities there are with respect to various criteria, the higher the chances for an environment where also commercial data centres are made part of energy management schemes as suggested by DC4Cities.

- Energy Efficiency: the development of energy efficiency in data centres in relation to energy efficiency in other areas of course affects the necessity to include data centres in smart cities into energy management and RES increasing schema. That means, if energy efficiency until the 2030s developed in a way, that energy consumption of DCs in smart cities becomes negligible, the necessity to include DCs in energy management schema and thus the DC4Cities marketing potential would be reduced. Until today, however, efficiency improvements in most cases have entailed absolute increases in energy consumption due to the so-called rebound effect, based on the Jevons’ paradoxon. If no game-changer comes into existence in the next decade, the progress of energy efficiency will most probably only alleviate the energy impact of mushrooming “big data”.

- Technical Development and “Big Data”: Apart from energy efficiency trends, there is a plethora of other technical trends that affect the magnitude of data that needs to be computed in the boundaries of smart cities. They relate to all areas of smartness in cities as mentioned in II.3.1.: Smart governance, economy, people, mobility, living and environment. What will be most probably common to all is the trend to create data in dimensions that former generations could never have foreseen. The Figure below gives an impression of this data growth. Trends that can be projected already

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from today’s perspective is a complete penetration of the electricity market with smart meters and smart city management schema as the ones sketched in III.1.3. – all these trends increase the scope for DC4Cities renewable energy adaption strategies.

**Figure 52 - Representation Of Byteunits [ROB01]**

- **Energy Storage:** Energy storage is an area of technical progress that is particularly important for the marketing chances of DC4Cities: on the one hand, generally the increase of storage capacity in the energy system reduces the necessity of demand side management like DC4Cities strategies. However, it again depends on the economic framework, to whom the energy storage in the physical energy infrastructure belongs: the higher the share of energy storage that belongs to data centres who thus can include storage into their DC4Cities strategies, the higher the market potential for DC4Cities. So, DC4Cities can be viewed either as competitive or as complementing technology to storage systems.

The penetration of the European landscape with smart cities, the progress of technologies fostering the emergence of smart cities and the development of energy efficiency of course amongst others depend on political guidelines and European research endeavours – so the size of the technical market potential for DC4Cities is impacted by the political and economic framework – and of course vice versa. This will become clear when impacting factors on the business potential of a DC4Cities market are illustrated:

- **Technical Potential:** Of course, as mentioned before, the business potential has its upper limits in the technical potential.

- **Smart Cities Policy:** The European Smart Cities Policy and roadmap aims at increasing the number of smart cities in Europe and the level of smartness by fostering research and supporting “lighthouse” smart cities (see II.3.1.). However, the current planning does not go way beyond 2030. In order to create a healthy environment for the penetration of smart cities and thus a market for DC4Cities, it would be helpful to increase the planning horizon and maybe organize subsidies for cities in dependence of measurable success facts like the share of RES or CO2 emissions per inhabitant. Measures like this might stimulate a city administration to implement the DC4Cities product portfolio including funds for an incentive framework.
like then RenEnergy contract system. In the same way national governments could support the emergence of smart and sustainable cities.

However, not only the national and trans-national smart city policies affect the chances for DC4Cities in smart city areas, but also the smart city administration itself can exert considerable influence on the emergence of a strong market for DC4Cities beyond mere computation of municipal data: industrial location policy might be used to set guidelines for a level of RES consumption, comparably to the RenPercent “objectives” that DC4Cities sets out. Or even the participation in a DC4Cities like energy management scheme might be a mandatory prerequisite for the settlement of a new data centre. The success of such strategies of course must be viewed in the context of the global smart cities and RES political strategies which influence the competitive position of participating DCs.

The more ambitious the overall smart city policies are, the better it is for the size of a DC4Cities market.

• **Energy Policy and Energy Market:** The volatility of energy prices heavily influences the operation of DCs which nowadays have a high share of energy cost at total operation cost. As projected in figure 53, the import prices of fossil fuels into the EU will steadily increase until 2030 by around 20% compared to the 2010 levels. The more the energy market system is constructed according to the vision in III.1. the higher the business scope for DC4Cities.

![Figure 53 - Assumptions for input prices of oil, coal and gas until 2050 [APO13]](image)

Particularly the outreach of today’s volatility of wholesale prices to retail pricing creates favourable conditions for DC4Cities. The more CO2 cost are internalized e.g via an ETS like scheme and the less nuclear energy is available due to the nuclear phase out, the easier the business case for DC4Cities: In an energy market that translates the volatility of wholesale prices partly to the final customers and smart city that as a supporting measure enacts special RenEnergy contracts, the limitations to the market size are only given by the criticalness of the services or the willingness-to-pay of the customers. But also the emergence of a culture of demand side aggregation fosters the dissemination of DC4Cities strategies. Using the EMA-SC, the energy management authority of a smart city, as an aggregator towards a dynamic capacity or energy only market would have a high impact on the potential success of DC4Cities not only with DCs computing municipal data, but with all DCs in the boundaries of the smart city.
• Data Centre Policy: As seen in II.2.1., to date, there is no EU wide specific DC legislation with regards to monitoring renewable energy source shares, general energy monitoring, capping or in any other kind or respect that would foster the participation in commercial or public DCs in DC4Cities schema. However, as The Data Centre Dynamics 2013 Workshop in London showed, the discussion in Europe is on its way. This leaves much hope for the coming decades that EU legislation e.g. regarding the monitoring of renewable energy shares, taxes according to CO2 emissions connected with DC power consumption and other measures might be established in the years to come. A general legislation framework for DCs that limits energy or CO2 consumption based e.g. on the service output of a DC would help develop the DC4Cities market and support its integration into a smart city DC4Cities scheme. The more energy management becomes “normal” and accepted in the society – which constitutes the final users of DC services – the easier it will be to set up DC4Cities in smart cities both for the processing of public and private data. However, additionally to regular DC legislation, public services DCs could be at the vanguard of a new generation of DCs by adhering to specific public administration by-laws that make the adherence of energy load to the supply of intermittent energy sources mandatory for public data centres.

If all these issues develop in a way positive for the economic viability of DC4Cities bases approaches to energy management, then these policies will lead to further increases in the flexibility of DCs’ business models as explained in III.2.1., especially with a continuing trend to cloud computing where also small DCs will be organized as internal clouds offering everything-as-a-service or through new business models that cannot be foreseen at the moment. This development will also lead to a dichotomy of huge data centres outside cities, located directly at favourable conditions like local cooling (“Iceland”) and nearly unlimited amounts of low-cost power (e.g. hydro in Sweden or other Northern countries) on the one hand and small to medium sized data centres in the vicinity of cities (all of them being smart) because of the necessity of data protection or low latency, the latter will all be more or less subject to power caps in one or the other form.

In lockstep with the society’s awareness of electrical power’s limits to the always-on-everything-now lifestyle, the nature of software services will change: It will be accepted that interaction may be interrupted or in some cases organized more like batch processes than they are nowadays (apart from mission critical or lifesaving services, of course). For instance: In the paper world, mail is delivered once or twice per day – nowadays, emails are delivered in most cases whenever they arrive; why not organize this according to the availability of solar or wind power: When there an abundance of power, the mail service is available as pushed; in times of low power, mail is delivered only in regular time steps (e.g. once per hour) or when pulled.

150 years ago, a cities data was managed by people at desks filing hardcopies in data closets. There was neither the technology nor the electricity available to support the administrative staff. Since then the data volume has increased sharply and will continue to do so exponentially in step with the “big data” phenomenon. Until around the turn of the millennium the electricity to compute the increasing amount of data seemed to be available always and everywhere. Since then we have perceived that it is not; however, it should not be forgotten, that the sun emits enough energy to feed the world – also the data world. It is our job to harvest it at the right time. In the suggested framework the DC4Cities portfolio will have a very strong position to support this endeavour.

V. OUTLOOK

Within the first iteration of the market analysis we have shown where and how DC4Cities could be marketed today or in the very near future by analysing the status quo of a market for DC4Cities. This was done from the perspective of the data centre, the energy system, and the smart city. However, due to several shortcomings in today’s general conditions, a potential, optimal future environment for DC4Cities was characterized next and the characteristics of data centres that are part of this environment was described. These findings concluded in a careful estimation where and to which extent a DC4Cities based product portfolio could be successfully introduced into the market today and in the future.

In the next version of the market study these generic findings will be refined. More precisely, further details from specific member states perspectives will be provided. This will help to better identify key factors relevant for the success of DC4Cities. Furthermore, more concrete findings particularly concerned with the revenue streams that the integration of the DC4Cities system will offer, will further help WP8 activities to elaborate the exploitation potential.

In addition, aspects on the legal framework will be examined. An adaptation of the legislation can play a key role in making the smart city concept a success. Political guidelines to foster the creation of a stable market for RES and thus for DC4Cities will therefore be proposed.
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