DEVELOPING A GIS-BASED CARBON FOOTPRINT ACCOUNTING METHODOLOGY FOR RESIDENTIAL BUILDINGS: THE CASE STUDY OF NILUFER DISTRICT IN BURSA

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ABSTRACT

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With the recent adoption of Paris Agreement, countries agreed to combat climate change and its impacts by making efforts to keep the global average temperature rise well below 2 °C and by striving for 1.5 °C by the end of this century. In line with this purpose, greenhouse gas emission reduction actions are integrated into environmental policies all over the world. Urban carbon footprint emerges as one of the key concepts of current global climate policies since urban areas are the major contributors to global GHG emissions today. To develop reliable urban emission reduction policies and mitigate the associated adverse effects, one first has to calculate the emission level as accurate as possible.

The main purpose of this study was to develop a GIS-based carbon footprint accounting methodology based on actual electricity and natural gas consumption figures of residential buildings in a pilot area to minimize the limitations caused by deficiencies in CF-related data generation and access; and to contribute to local policy-making by providing useful tools and results to decision-makers. Within this scope, three types of residential heating systems that predominate in Turkey were focused on, namely: (i) individual heating systems, (ii) central heating systems and (iii) district heating systems.

Residential carbon footprint of six selected neighborhoods in Nilüfer District of Bursa Province was calculated by utilizing the GIS database of the pilot area. Although convenience of using a GIS software in carbon footprint accounting was observed to a certain extent, some corrections and modifications were required to obtain a complete GIS database that would serve the purpose of this study.

Calculations were done based on actual natural gas and electricity consumption values of sample buildings and for each year between 2014-2017. According to the results, residential carbon footprint in the pilot area ranged from 93.14 to 119.52 $ktCO_2$ and the per capita residential carbon footprint ranged from 0.99 to 1.27 tCO_2 between 2014-2017. A more in-depth analysis of the results was then made by using spatial analysis tools to better discuss the outcomes; and consequently, useful conclusions for local policy-makers and future studies were drawn.

Keywords: GHG emissions, urban carbon footprint, Geographic Information Systems, spatial analyses, urban policy-making

ÖZ

KONUTLAR İÇİN CBS TABANLI BİR KARBON AYAK İZİ HESAPLAMA METODOLOJİSİ GELİŞTİRİLMESİ: BURSA'DA NİLÜFER İLÇESİ ÖRNEĞİ

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Yakın zamanda Paris Anlaşması'nın kabul edilmesiyle birlikte, iklim değişikliği ve etkileriyle mücadele etmek adına, bu yüzyılın sonuna kadar küresel sıcaklık artışının 2 °C'nin olabildiğince altında tutulması ve hatta 1,5 °C ile sınırlandırılması hedeflenmiştir. Bu kapsamda, sera gazı salımı azaltma eylemlerinin tüm dünyada çevre politikalarına entegre edildiği görülmektedir. Kentler, günümüzde küresel sera gazı salımlarına en fazla katkıda bulunan unsurlar olduğundan, kentsel karbon ayak izi güncel küresel iklim politikalarının yapı taşlarından biri olarak öne çıkmaktadır. Kentsel emisyonları ve buna bağlı olumsuz etkileri azaltmayı hedefleyen sağlıklı politikalar geliştirmek için ilk olarak karbon ayak izini olabildiğince doğru hesaplamak gerekir.

Bu çalışmanın amacı, karbon ayak izi ile ilgili veri üretme ve veriye erişimdeki zorlukların neden olduğu kısıtlamaların en aza indirgenebilmesi için, gerçek elektrik ve doğal gaz tüketim değerlerine dayanan, CBS tabanlı bir karbon ayak izi hesaplama metodolojisinin geliştirilmesidir. Aynı zamanda, karar vericilere faydalı olacak araç ve sonuçlar sağlanarak yerel politikalara katkıda bulunulması da hedeflenmektedir. Bu kapsamda, Türkiye'de ağırlıklı kullanılmakta olan üç farklı konut ısıtma sistemi üzerinde çalışılmıştır: (i) tekil (kombili) ısıtma sistemleri, (ii) merkezi ısıtma sistemleri ve (iii) bölgesel ısıtma sistemleri.

Bursa İli Nilüfer İlçesi'nde seçilen altı mahalleden oluşan pilot alandaki konutlara ait karbon ayak izi, bu alana ait CBS veri tabanından yararlanılarak hesaplanmıştır. Her ne kadar CBS yazılımı kullanmanın karbon ayak izi hesaplamasında sağladığı kolaylıklar gözlenmişse de, çalışmanın amacına tam anlamıyla hizmet edebilecek, bütün bir CBS veri tabanı elde edebilmek için çalışma esnasında veri tabanında bazı düzeltme ve değişikliklerin yapılması gerekli olmuştur.

Hesaplamalar, her bir konut tipinden örnek olarak seçilen binalara ait gerçek doğalgaz ve elektrik tüketim değerlerine dayanarak, 2014-2017 yılları arasındaki her bir yıl için gerçekleştirilmiştir. Elde edilen sonuçlara göre, pilot bölgedeki konutlara ait karbon ayak izinin 2014-2017 yılları arasında 93,14 ile 119,52 ktCO_2, konutlara ait kişi başı karbon ayak izinin ise 0,99 ile 1,27 tCO_2 arasında değiştiği görülmüştür. Hesaplamaların akabinde, sonuçların daha iyi tartışılabilmesi için CBS mekânsal analiz araçları kullanılarak daha derinlemesine bir analiz yapılmış, yerel politika yapıcılar için faydalı olacak ve gelecekteki çalışmalara ışık tutacak nitelikte sonuçlar elde edilmiştir.

Anahtar kelimeler: Sera gazı salımları, kentsel karbon ayak izi, Coğrafi Bilgi Sistemleri, mekânsal analizler, kentsel politikalar

To my most precious moments and memories, with gratitude…

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AFOLU	Agriculture, Forestry and Other Land Use
C40	C40 Cities Climate Leadership Group
CB	Consumption-based
CCAP	Climate Change Action Plan
CF	Carbon Footprint
CH	Central Heating
CO_2	Carbon Dioxide
CoM	Covenant of Mayors
COP	Conference of Parties
COV	coefficient of variation
DH	District Heating
DPSC	Direct Plus Supply Chain
EC-CoM	European Commission Covenant of Mayors
EF	Emission Factor
EMRA	Energy Market Regulatory Authority
ESRI	Environmental Systems Research Institute, Inc.
GHG	Greenhouse gas
GIS	Geographical Information Systems
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
GWP	Global Warming Potential

ICLEI	Local Governments for Sustainability
IEAP	International Local Government GHG Emissions Analysis Protocol
IH	Individual Heating
IPCC	Intergovernmental Panel on Climate Change
IPPU	Volume 3 Industrial Processes and Product Use
ISC	International Standard for Determining Greenhouse Gas Emissions for Cities
$ktCO_2$	kiloton carbon dioxide
kWh	kilowatt hour
LCA	Life Cycle Assessment
MM	Metropolitan Municipality
MoEU	Ministry of Environment and Urbanization
NGO	Non-Governmental Organization
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan
SH	Single House
Sm^3	standard cubic meter
tCO_2	ton carbon dioxide
TSI	Turkish Statistical Institute
UEDAŞ	Uludağ Elektrik Dağıtım A.Ş.
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

CHAPTER 1

INTRODUCTION

With the adoption of Paris Agreement in late 2015, countries agreed to combat climate change and its impacts by making efforts to keep the global average temperature rise well below 2 °C and by striving for 1.5 °C by the end of this century (UNFCCC, 2018). In line with this objective, greenhouse gas (GHG) emission reduction actions are integrated into environmental policies all over the world. Carbon footprint is one of the concepts that emerged as a result of such local and global environmental policies against climate change and its impacts; and it became a popular concept since then. It is worth mentioning that the terms *"carbon footprint"*, *"carbon footprinting"* and *"carbon footprint accounting"* are often interchangeably used in the literature and also in this thesis. The main and simplest idea behind carbon footprinting is to understand the actual impact of anthropogenic activities on the environment. Carbon footprint (CF) accounting has not been established by research; rather it was promoted by companies, non-governmental organizations (NGOs) and private initiatives. Consequently, the CF concept ended up having several definitions and calculation methods (UNESCO, 2012). However; a common definition of CF would be "a measure of the impact human activities has on the environment in terms of the amount of greenhouse gases produced, measured in tonnes of carbon dioxide." (Wiedmann & Minx, 2008).

Today, CF has become a commonly used concept, despite its lack of scientifically accepted and universally adopted guidelines. There is a wide range of entities for which the CF can be calculated, including processes, products, companies, industry sectors, individual and groups of consumers; and geographically delineated areas (UNESCO, 2012).

Urban CF accounting is one of the key concepts of current global climate policies since urban areas have a substantial amount of contribution to global GHG emissions today. In terms of surface area, cities do not occupy a large area on the Earth: only 2% of the world's landmass. However, with the ever-increasing urbanization, industrialization and resource consumption, almost 80% of the energy produced worldwide is consumed in urban areas. Consequently, urban areas have become the major contributors to global GHG emissions as they are responsible for almost 80% of the emissions (Lombardi, Laiola, Tricase, & Rana, 2017). Besides being the major contributors to global GHG emissions with these figures, cities are also the most vulnerable areas in the face of climate change and its impacts. Unfortunately, 70% of cities are already exposed to the impacts of climate change, and nearly all are somehow at risk. In addition to the physical effects of climate change, devastating financial effects can also arise since extreme events result in unforeseen expenditures (C40 Cities, 2012). Unfortunately, the urban growth does not decelerate, and urban population is expected to reach 70% of the world's population by 2050 (World Bank, 2010).

Despite their significant contribution to global GHG emissions, cities are also believed to provide solutions to climate-related risks if urban density is considered as an opportunity. In line with this "global effects arise from local actions" approach, international alliances are established around the world with the purpose of creating coalition of cities and local governments to reduce GHG emissions and climate risks in cities; and eventually in the world. The most known of these organizations are namely the *"ICLEI – Local Governments for Sustainability"* (hereinafter referred to as "ICLEI"), *"C40 Cities Climate Leadership Group"* (hereinafter referred to as "C40"), and the *"Global Covenant of Mayors (CoM) for Climate & Energy"*, which brings together the *"EU's Covenant of Mayors"* and the *"Compact of Mayors"*. Connecting hundreds and thousands of cities and local governments from all over the world, these global networks provide a platform for collaborating, sharing knowledge and taking actions against climate change. Within this scope, the member cities or local governments are committed to declare their action plans, through which their urban GHG inventories are also presented. The number of member countries to such networks is constantly increasing. Turkey is also a member of some of these networks and is committed to declare its GHG inventories, which will be explained in more detail in the following chapters.

Urban GHG emissions reporting first began to be implemented in early 1990s by "*ICLEI – Local Governments for Sustainability*", with their urban emission quantification and reduction campaign (Ibrahim, Sugar, Hoornweg, & Kennedy, 2012). Today, urban CF is recognized as one of the most valuable decision-making tools for policy makers in terms of environmental sustainability of a city as it enables detecting the most emission-intensive sectors and taking measures accordingly (Lombardi, Laiola, Tricase, & Rana, 2017). In the past 15 years, many other organizations started to establish urban GHG inventories, leading to discussions about methodological consistencies. In their study conducted in 2012 as a comparative analysis of urban GHG inventory methodologies, Ibrahim et al. underlined the significant gap of methodological consistency and standardization at the urban level and stressed the growing need for harmonization (Ibrahim, Sugar, Hoornweg, & Kennedy, 2012). Although some efforts were made to establish a harmonized and globally accepted protocol, it was emphasized in a very recent study by Lombardi et al. that the aforesaid gap is still present, and it should be closed in the near term to better compare urban CFs and take global actions (Lombardi, Laiola, Tricase, & Rana, 2017).

All things considered, it can be clearly concluded that to be able to develop reliable urban emission reduction policies and mitigate the associated adverse effects, one first has to calculate the emission level as accurate as possible. In this thesis, the potential of developing such accounting methodology for residential buildings was examined by making use of Geographical Information Systems (GIS) software. The detailed objectives of the study are mentioned in the following section.

1.1 Objective and Expected Contributions of the Thesis

The main objective of this study was to develop a GIS-based carbon footprint accounting methodology based on actual electricity and natural gas consumption data of residential buildings in a pilot area to minimize the limitations caused by deficiencies in CF-related data generation and access; and to contribute to local policy-making by providing useful tools and results to decision-makers.

The expected contributions of this thesis include:

- obtaining more realistic and accurate CF results by using actual consumption data and actual floor areas in calculations, compared to the urban GHG inventories that do not use actual consumption or floor area data,
- providing a useful carbon inventorying and monitoring tool to municipalities, and
- performing a more in-depth analysis of the results through spatial analyses and deriving sound policy implications on how to design and manage residential areas in a way to minimize carbon emissions.

1.2 Contents and Structure of the Thesis

This thesis comprises five chapters in total, which will be outlined in this section. Subsequent to the introduction, the main international urban GHG inventory frameworks are summarized, the urban GHG inventories prepared in Turkey until today are presented and former GIS-based CF studies from the literature are mentioned in Chapter 2. Then, the methodology followed for this study is presented in Chapter 3. After that, calculations are provided, and the results are discussed in Chapter 4. The final chapter concludes the thesis by summarizing the findings, providing recommendations for policy-making and stating recommendations for future studies.

CHAPTER 2

CARBON FOOTPRINT ACCOUNTING: BASICS, GUIDELINES AND FORMER STUDIES

Carbon footprint accounting is a technique to interpret and quantify the actual impact of anthropogenic activities on the environment. It should be mentioned that the terms *"carbon footprint accounting"* and *"GHG emissions inventorying"* are often interchangeably used in the literature and also in this thesis.

Current CF calculation methodologies consist of numerous actual standards, standard-like guidelines, and guidebooks; as well as various methodologies being developed by research groups. The CF accounting methodologies are an important tool for institutional, industrial, regional, national and global GHG management. Hence, the studies and efforts are towards developing standardized frameworks for CF accounting and reporting, which have to be accurate, comprehensive and comparable (Lombardi, Laiola, Tricase, & Rana, 2017).

In this Chapter, first, the general structure that is common to almost all CF accounting methodologies is introduced to provide a better understanding. In this context, the scopes of emissions, accounting perspectives and calculation approaches are addressed as follows:

A) Scopes

Scopes are the most commonly-used and standardized definitions for the classification of direct and indirect emissions to help facilitate the emissions accounting process. They were first elaborated in 2001 by the World Business Council for Sustainable Development (WBSCD) and World Resources Institute (WRI) for corporate emissions accounting and were divided into three groups. In

2014, they were extended to city-scale (Lombardi, Laiola, Tricase, & Rana, 2017; UNESCO, 2012; WRI, C40, & ICLEI, 2014) (Lombardi, Laiola, Tricase, & Rana, 2017) (UNESCO, 2012) (WRI, C40, ICLEI, 2014). Today, the widely accepted scope classification, which is referred to as "WRI definitions of scopes" is as follows:

- **Scope 1: Direct GHG emissions** are those resulting from;

i. sources owned or controlled by the company, in case of corporate emissions (e.g. from combustion in owned or controlled boilers, furnaces or vehicles); and

ii. the local or territorial activities and sources within the boundaries of a city, in case of urban emissions (e.g. fossil fuel combustion, waste and wastewater, agriculture, forestry and other land use, industrial processes and product use).

- **Scope 2: Energy indirect GHG emissions** are the emissions arising from;

iii. the generation of purchased electricity consumed by the company, in case of corporate emissions. These emissions physically occur at the electricity generation facility itself.

iv. the consumption of electricity, heat, steam and/or cooling supplied by grids which may or may not cross the city boundary.

- **Scope 3: Other indirect GHG emissions** are;

v. a result of company activities; yet they occur from sources not owned or controlled by the company (e.g. extraction and production of purchased materials, transportation of purchased fuels, and use of products and services sold by the company).

vi. All other emissions that occur outside the city boundaries due to activities taking place within the boundaries (e.g. marine and aviation transport, import and export emissions, out-of-boundary electricity transmission and distribution, out-of-boundary waste and wastewater) (WRI, C40, ICLEI, 2014) (WBCSD and WRI, 2004).

B) Accounting Perspectives

Accounting perspectives define which emissions should be taken into account during CF calculation. There are three main accounting perspectives, namely the "territorial", "consumption-based" and "production-based" perspectives. A combined perspective can also be used for urban carbon footprint (UCF) studies to provide a better representativeness of the urban contribution to climate change (Lombardi, Laiola, Tricase, & Rana, 2017).

C) Calculation Approaches

Calculation approaches define how to gather the necessary GHG data for CF calculations. The three main approaches that are used for CF calculations are named as "bottom-up", "top-down" and "hybrid" approaches (UNESCO, 2012). More detail on the sub-topics of accounting perspectives and calculation approaches are provided in APPENDIX A.

Although CF is a widely-used instrument, there is not much uniformity in its calculation methods. Among these methods, the main differences are in:

- The scope of the study (generally, indirect emissions are excluded),
- The gases included,
- The weighting[1] of these gases to attain CO_2-equivalents,
- The system boundaries chosen (UNESCO, 2012)

The focus of this thesis is urban CF; and more specifically residential CF due to electricity and natural gas consumption. In fact, urban CF has numerous components and sub-topics other than residential energy consumption. These topics involve community-scale activities and sectors such as stationary energy generation, transportation, waste, industrial processes, product use, agriculture, forestry and other land use activities. The reasons for specifically focusing on electricity and natural gas consumption in residential buildings include the following:

[1] "Weighting" here refers to Global Warming Potential (GWP) coefficients/weighting factors used to calculate CO_2-equivalents (CO_2e) of non-CO_2 GHG emissions.

- Stationary energy sources are one of the major contributors to urban CF, within which residential sector has a large share.
- In today's developing world, residential sector is one of the most energy-intensive sectors in cities.
- There is an increasing energy demand in the residential sector and Turkey is highly dependent on foreign natural gas resources; therefore, understanding the CF results of residential energy consumption is a must for taking actions on energy efficiency.
- Nilüfer District has a high housing estate density, which is expected to increase in the coming years (Ruzgar Danismanlik, 2016).

In the rest of this chapter, the principal international urban GHG inventory frameworks are summarized in Section 1.3., in line with the focus of this thesis (see APPENDIX B for a summary of international frameworks used for levels other than urban-level CF accounting). Then, highlights from the urban GHG inventories prepared in Turkey until today are presented in Section 1.4. Finally, former GIS-based CF accounting studies from the literature are mentioned in Section 1.5.

1.3 Urban GHG Emission Inventory Frameworks

The importance of urban CF accounting and its place on the agenda were discussed in detail in Section 1. Since the objective of this study is to develop a GIS-based, residential CF accounting methodology based on actual electricity and natural gas consumption figures in a pilot area, examples to key standardized methodologies proposed by international institutions for urban CF accounting are briefly and chronologically introduced in this section to provide a better insight. The key points of methodologies regarding the indoor heating and electricity consumption in the residential sector will be much discussed in line with the purpose of this study.

1.3.1 International Local Government GHG Emissions Analysis Protocol (IEAP) by ICLEI

Developed by ICLEI in 2009, the *International Local Government GHG Emissions Analysis Protocol* (hereinafter referred to as the "IEAP") aims primarily to assist local governments in quantifying emissions from their internal operations along with community-based emissions within the geopolitical boundaries. The Protocol draws the framework for GHG management as follows:

1. A GHG emissions inventory should be established
2. A reduction target should be set
3. A strategy should be developed for emissions reduction
4. Progress should be monitored, and results should be reported (ICLEI, 2009).

Principles and Implementation

The IEAP requires local government GHG inventories to include two parts as the internal operations of local government itself and the community emissions. It follows the main principles that are commonly adopted by other major standards and guidelines: *relevance, completeness, consistency, transparency* and *accuracy*.

Scope of the Inventory

The GHGs that should be quantified in a local government GHG inventory are the "six Kyoto gases", which are listed below:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- perfluorocarbons (PFCs)
- hydrofluorocarbons (HFCs)
- sulfur hexafluoride (SF_6).

Among the GHGs listed above, the most critical ones are generally the emissions of CO_2, CH_4 and N_2O from fossil fuel combustion, electricity generation, waste disposal and wastewater. The IEAP requires the GHGs to be converted into CO_2e during calculations based on the latest 100-year Global Warming Potential (GWP) coefficients produced by the IPCC.

System Boundary

Local governments are entities with multiple functions such as developing policies and providing several services. Therefore, the IEAP defines two separate boundaries for emissions accounting as i) "organizational boundary" for the functions under their own control; and ii) "geopolitical boundary" for the activities occurring within the area of the local government's jurisdictional authority (ICLEI, 2009).

Data

As indicated in the IEAP, the level of data aggregation depends on data availability as well as the required level of detail for the planned action. Therefore, the users should be able to balance the data requirements with the wanted results when composing an emissions inventory.

Before collecting data, local governments should examine the range of available data sources and should select a "base year" against which the changes in emissions are monitored. The IEAP mentions that if accurate data of adequate detail can be gathered, establishing an emissions inventory for the earliest year possible is good practice. Three tiers are defined for the varying levels of emission factor and activity data precision, in line with the IPCC's tier approach (ICLEI, 2009).

Emissions Scopes

As majority of the methodologies do, the IEAP also classifies the emissions into three scopes, which result in minor differences when applied to government operations and community emissions. Local governments should at least report the total Scope 1 and Scope 2 emissions in keeping with the Protocol. As can be seen in Table 2-1 below, emissions from indoor heating by natural gas and electricity consumption of residential sector are classified as scope 1 and scope 2, respectively. It should be noted that emissions from district heating systems for residential indoor heating purposes are mostly classified under scope 2 rather than scope 1.

Table 2-1. Stationary Energy-Sourced Emissions as per the IEAP

Macro Sector (UNFCCC)	**Community Sector (ICLEI)**	**Scope 1 Emissions**	**Scope 2 Emissions**	**Scope 3 Emissions**
Stationary Energy	Residential Commercial Industrial	• Utility-delivered fuel consumption • Decentralized fuel consumption • Utility-consumed fuel for electricity/heat generation	• Utility-delivered electricity/heat/ steam cooling consumption • Decentralized electricity/heat/steam consumption	• Upstream/ downstream emissions (e.g. mining/transport of coal)

Source: (ICLEI, 2009)

Calculation

The IEAP requires an emission factor-based accounting methodology, which means the emissions are calculated according to Equation (1) below:

$$GHG\ emissions\ = Activity\ data\ (AD)\ x\ Emission\ Factor\ (EF) \quad (1)$$

Guidance on the use of appropriate activity data and emission factors, and their common sources are provided in the IEAP. As per the tier approach, emission factors and activity data are categorized under three tiers based on their complexity, and it is deemed good practice to report the tiers for all emissions sources accounted in the inventory (ICLEI, 2009).

1.3.2 How to Develop a Sustainable Energy Action Plan (SEAP) Guidebook Part II - Baseline Emissions Inventory (BEI) by the European Commission Covenant of Mayors

Developed by the European Commission Covenant of Mayors (EC-CoM) in 2010, the *How to Develop a Sustainable Energy Action Plan (SEAP) Guidebook Part II - Baseline Emissions Inventory (BEI)* (hereinafter referred to as the "BEI") aims to guide local authorities in elaborating their BEI, which quantifies the amount of CO_2 emitted due to energy consumption in the territory of the Covenant party in the baseline year (i.e. the year against which the outcomes of the reduction targets are to be compared). By doing so, prioritization of reduction measures is enabled (Covenant of Mayors, 2010).

Principles and Implementation

For its implementation, the BEI delivers two approaches for emission factor selection: using the standard emission factors based on IPCC principles, or using the LCA emission factors. Mentioning the advantages and challenges of both approaches, the BEI presents default emission factors that can be used if the standard approach is selected. The LCA approach may especially be challenging as it includes emissions from all life cycle steps and obtaining data on the upstream emissions can be problematic.

Scope of the Inventory

The BEI has a major focus on energy. GHGs to be included in the BEI depend on the chosen sectors and emission factor approach. If the standard approach is followed, including only CO_2 emissions is sufficient since the other gases are of negligible importance as per the IPCC principles (Covenant of Mayors, 2010). However, other GHGs can also be included if deemed necessary or if the LCA approach is chosen. In such cases, these emissions should be converted into CO_2e based on their GWP values.

System Boundary

The geographical boundaries of the inventory are defined as the administrative boundaries of the local authority. The below listed emissions are quantified within the scope of the BEI:

1. Direct emissions due to fuel combustion in the buildings, equipment/facilities and transportation sectors,
2. (Indirect) emissions from generation of electricity, heat, or cold that are consumed in the territory, and
3. Other direct emissions occurring in the territory.

It should be noted that emissions from indoor heating by natural gas and electricity consumption of residential sector are recommended to be included in the BEI (Covenant of Mayors, 2010).

Data

For the collection of activity data on final energy consumption of residential buildings, the BEI presents various approaches, and states that a combination of them may be necessary in some cases. The first approach suggested is getting data from the market operators; however, emphasis is made on its difficulties since the energy consumption data have become commercially sensitive after the liberalization of gas and electricity market. In fact, this is the case with the electricity market in Turkey today. Obtaining data on electricity consumption became quite difficult after the privatization of electricity distribution companies. The BEI suggests getting data from other entities such as ministries, agencies or regulatory authorities for gas and electricity as the second approach. Making inquiries directly to the consumers is recommended as a last resort.

The BEI defines two levels for emission factor precision as “standard” or “LCA” emission factors; however, it requires the activity data to be city-specific; and disapproves the estimations made based on national averages (Covenant of Mayors, 2010).

Emissions Scopes

The WRI definitions of emissions scopes are not recognized, but are only referred to, by the BEI.

Calculation

The BEI requires an emission factor-based accounting methodology, which means the emissions are calculated according to Equation (1).

1.3.3 International Standard for Determining Greenhouse Gas Emissions for Cities by UNEP, UN-HABITAT and World Bank

The *International Standard for Determining Greenhouse Gas Emissions for Cities* (hereinafter referred to as the "ISC") was jointly developed by UNEP, UN-HABITAT and World Bank in 2010. Rather than providing a distinct accounting methodology, the ISC aims to tackle methodological variation issues by setting a common standard for urban GHG emissions inventorying (UNEP, UN-HABITAT, World Bank, 2010).

Principles and Implementation

Urban GHG inventories should follow the most recent IPCC guidelines, principles and methodologies as per the ISC. However, for the accounting of out-of-boundary emissions due to activities in cities, the Corporate Standard by WBCSB and WRI is followed by the ISC. The ISC also includes standard tables for reporting urban emissions, which contains information on emission factors and activity data used during calculations. With this standard reporting format, the ISC aims the reporting of local governments to be in conformance with national inventories. The format is particularly suggested for the use of cities with more than 1 million population (UNEP, UN-HABITAT, World Bank, 2010).

Scope of the Inventory

The ISC requires six Kyoto gases along with any other relevant GHGs to be reported in urban GHG inventories. GHGs should be converted into CO_2e based on the most recently published GWP coefficients of the IPCC, while being reported.

System Boundary

The inventory boundary is defined as the territorial boundaries of the city, to which the Scope 1, 2 and 3 emissions defined by the WRI are attributed.

Data

Following the "Tier approach" of the IPCC methodology, the ISC defines varying levels of activity data and emission factor precision.

Emissions Scopes

The WRI definitions of emissions scopes are recognized by the ISC. Emissions due to activities within the territorial boundary (i.e. Scope 1 emissions) are calculated as well as the indirect/embodied out-of-boundary emissions as a result of activities in cities (i.e. Scope 2 and 3 emissions).

Calculation

According to the ISC, calculation of urban GHG emissions should be based on the most recent IPCC Guidelines (UNEP, UN-HABITAT, World Bank, 2010).

1.3.4 PAS 2070:2013 + A1:2014 Specification for the assessment of greenhouse gas emissions of a city by BSI

The *PAS 2070:2013 + A1:2014 Specification for the assessment of greenhouse gas emissions of a city* (hereinafter referred to as "PAS 2070") was first published in 2013 by BSI and was amended in 2014. PAS 2070 aims to provide specifications for urban GHG emissions assessment by following globally recognized accounting and reporting principles (BSI, 2014).

Principles and Implementation

The PAS 2070 is proposed for international application for use by municipal or national governments, academic researchers, consultants and other organizations or people that quantify urban GHG emissions. It offers two separate yet complementary methodologies for urban emissions assessment, which identify cities as both consumer and producers of goods and services. The methodologies are named as the "direct plus supply chain (DPSC) methodology" and the "consumption-based (CB) methodology".

The DPSC methodology is based on the *Global Protocol for Community-Scale Greenhouse Gas Emissions (GPC)* by WRI, and it covers direct emissions from activities within the city boundary as well as indirect emissions from the consumption of grid-supplied electricity, heating, cooling, transboundary travel and consumption of main goods and services produced out-of-boundary (e.g. water supply and food). The CB methodology allocates the emissions to the final consumers, and accounts for direct and life cycle emissions for all goods and services consumed by the city's residents (BSI, 2014).

Application of PAS 2070 for urban GHG emissions accounting is illustrated as a case-study for London in 2014 by BSI in the *"Application of PAS 2070 – London, United Kingdom"*, which is a publicly available supplementary document to the standard. In this document, emissions from indoor heating by natural gas and electricity consumption of residential sector are calculated by using the DPSC methodology. According to the calculations, the greatest emissions source of London was the energy use in buildings, which corresponded to 50% of London's total emissions. Combustion of primary fuels from residential buildings, almost all of which is natural gas, resulted in 9.28 Mt CO_2e while 6.54 Mt CO_2e were released due to residential electricity consumption. Also, 0.25 Mt CO_2e were released due to Scope 2 heating, i.e. from district heating systems (BSI, 2014).

Scope of the Inventory

The PAS 2070 covers the emissions of six Kyoto gases by excluding direct removals of GHGs from the atmosphere, such as carbon sequestration in soil and vegetation. GHGs should be converted into CO_2e based on the most recently published IPCC 100-year GWP coefficients.

System Boundary

PAS 2070 defines the inventory assessment boundary as the city boundary for both the DPSC and CB methodologies. Time period of an assessment is stated as one calendar/financial year, or any other continuous 12-month period specified (BSI, 2014).

Data

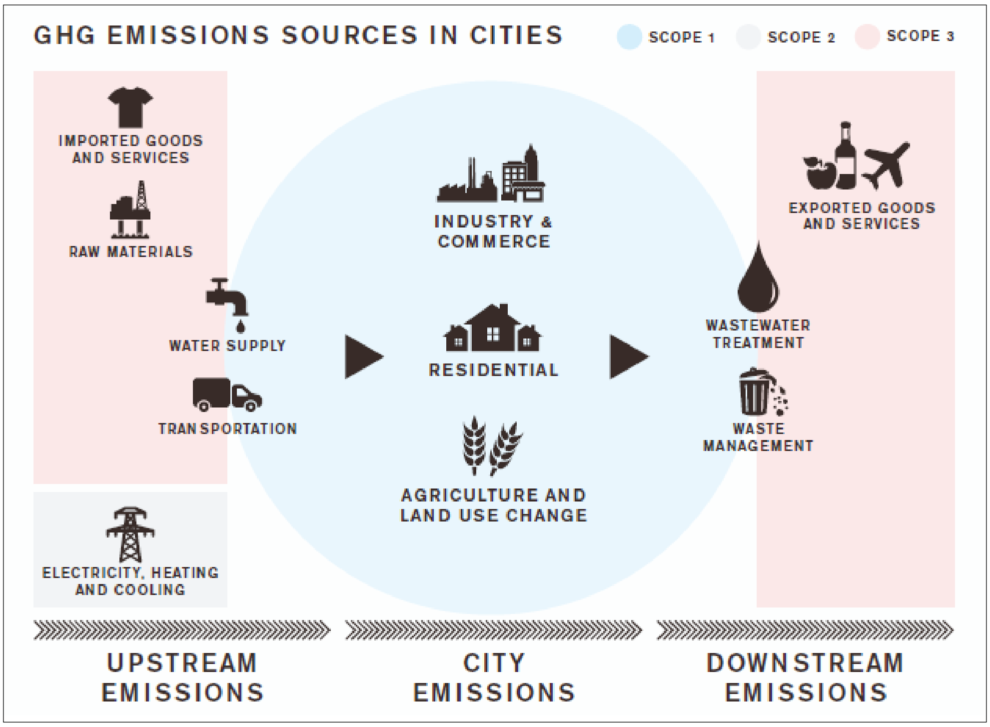
Emissions from indoor heating by natural gas and electricity consumption of residential sector are calculated by following the DPSC methodology, which requires disaggregation of collected data by i) residential buildings and ii) commercial, industrial and government buildings. Data used for estimation of fuel use shall be chosen in the below order of preference:

1. Energy use data from energy providers,
2. City-specific survey use data provided by peer reviewed studies (i.e. academic journals, government department reports etc.),
3. National government statistics,
4. National survey use data from peer-reviewed studies.

Accordingly, activity data shall be collected for the use of natural gas, oil, coal and any other fuels used for heating or lighting purposes (BSI, 2014).

Emissions Scopes

The DPSC methodology adopts the WRI definitions of emissions scopes, as illustrated in Figure 2-1. However, these scope definitions are not valid for the CB methodology. As can be seen, emissions from indoor heating by natural gas and electricity consumption of residential sector are classified as scope 1 and scope 2, respectively. District heating is also classified as scope 2 as per PAS 2070 (BSI, 2014).



Source: (BSI, 2014)

Figure 2-1. Urban GHG emissions sources with respect to Scopes

Calculation

PAS 2070 requires an emission factor-based accounting methodology, and thus the emissions are calculated according to Equation (1).

1.3.5 Global Protocol for Community-Scale Greenhouse Gas Emission Inventories – An Accounting and Reporting Standard for Cities by WRI, C40 and ICLEI

The *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories – An Accounting and Reporting Standard for Cities* (hereinafter referred to as the "GPC") is the most recent global reporting standard published in December 2014 as a result of the joint effort between C40, WRI and ICLEI. It is regarded as the international best practice standard for city-level GHG emissions inventories by C40 (C40 Cities, 2017). Consistent with IPCC Guidelines, it aims to provide a robust and clear framework against the inconsistencies and dissimilarities among urban GHG inventory methodologies. The GPC has been adopted by the Global Compact of Mayors as one of their main tools for improving urban GHG inventory reporting (WRI, C40 and ICLEI, 2014).

Principles and Implementation

The GPC can be used by anyone who wants to quantify and assess the emissions within a geographically defined, subnational area. It requires summing up and reporting urban emissions by using two separate, yet complementary approaches called “scopes framework” and “city-induced framework”. The former requires summing up all emissions by scope 1, 2 and 3, and thus enabling separate accounting of all emissions produced within the geographic boundary of the city; while the latter requires totaling the emissions related to activities occurring within the geographic boundary of the city. The city-induced framework also covers certain scope 1, 2 and 3 emission sources that are common to most cities and that can be quantified by standardized methods. The GPC follows the main principles that are commonly adopted by other major standards and guidelines, which are *relevance, completeness, consistency, transparency* and *accuracy* (WRI, C40 and ICLEI, 2014).

Scope of the Inventory

The GPC intends to account for the emissions of six Kyoto gases and nitrogen trifluoride (NF_3). GHGs covered should be converted into CO_2e based on the most recent IPCC 100-year GWP coefficients (WRI, C40 and ICLEI, 2014).

System Boundary

The GPC provides flexibility to the determination of inventory boundary by stating that it depends on the purpose. Accordingly, the boundary can be set as the administrative boundary of a local government, a borough within a city, a metropolitan area, a town, a district, a county, a province, a state or any other geographically identifiable entity. The GPC is intended to represent GHG emissions in one reporting year, and suggests the inventories to be updated annually, based on the latest available data (WRI, C40 and ICLEI, 2014).

Data

Indoor heating by natural gas and electricity consumption of residential sector are listed within the sub-sector named "residential buildings" under the "stationary energy" emission sector. Two reporting levels are provided as an option by the city-induced framework as "BASIC" and "BASIC+", the former being less challenging in terms of data collection and calculation. The residential buildings sector is reported at the BASIC level since scope 1 and 2 emissions from stationary energy are covered by BASIC reporting.

According to the GPC, data can be collected from several sources including governmental departments, statistics agencies, national GHG inventory reports, universities, research organizations, scientific articles, reports, journals, sector experts and stakeholder institutes. Overall, local and national data are preferred over international data; and publicly-available and reliable sources are favored. In contrast to BEI, the GPC allows the adjustment of activity data that do not correspond to the boundary or time period of the inventory, by using a scaling factor. For example, data from national or regional level can be scaled to city-level by using the scaling methodology and adjusting the available data to the required inventory data. The GPC specifies the features of emission factors to be boundary-related, activity-specific, and obtained from reliable government, industry or academic sources. The IPCC default emission factors or other standard values by international institutions should be used if there is no available data source for the specific area of study (WRI, C40 and ICLEI, 2014).

To define and manage data quality, the GPC refers to the tier approach of the IPCC methodology where applicable; however, it also defines its own quality indicators to help assess the data quality as "High (H), Medium (M) or Low (L)". The GPC data quality indicators are presented in Table 2-2.

Table 2-2. Data quality indicators of the GPC

Data Quality	Activity Data	Emission Factor
High (H)	Detailed activity data	Specific emission factors
Medium (M)	Modeled activity data using robust assumptions	More general emission factors
Low (L)	Highly-modeled or uncertain activity data	Default emission factors

Source: (WRI, C40 and ICLEI, 2014)

Emissions Scopes

The GPC adopts the WRI definitions of emissions scopes; and refers to Scope 1 emissions as "territorial emissions". Emissions from indoor heating by natural gas and electricity consumption of residential sector are classified as scope 1 and scope 2 emissions, respectively. In addition, district heating is classified as scope 2 as per the GPC.

Calculation

The GPC requires an emission factor-based accounting methodology for most emission sources, and thus the emissions are calculated according to Equation (1). Unless otherwise stated, calculation methodologies presented by the GPC are consistent with the IPCC Guidelines. Sources for activity data are presented below, in the order of preference:

1. Real consumption data by fuel type and sub-sector,
2. A representative sample set of real consumption data from surveys,
3. Modeled consumption data,
4. Incomplete or aggregate real consumption data,
5. Regional/national consumption data scaled down using scaling factors such as population (WRI, C40 and ICLEI, 2014).

The methodology reference of the GPC for the quantification of emissions from indoor heating by natural gas and electricity consumption of residential sector are presented in Table 2-3.

Table 2-3. Methodology Reference of the GPC

Sector	Emission Source	Scope	Approach	Activity Data	Emission Factors
Stationary Energy	Fuel combustion within city boundaries	1	Fuel Consumption	Amount of fuel consumed	Mass GHG emissions per unit fuel
	Consumption of grid-supplied energy consumed within city boundaries	2	Grid-Energy Consumption	Amount of grid-supplied energy consumed	Mass GHG emissions per unit grid-supplied energy (grid specific emission factor)

Source: (WRI, C40 and ICLEI, 2014)

1.3.6 2006 IPCC Guidelines for National Greenhouse Gas Inventories

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (hereinafter referred to as "IPCC Guidelines") are prepared by the Task Force on National Greenhouse Gas Inventories (TFI) of the Intergovernmental Panel on Climate Change (IPCC), and is the updated version of the earlier 1996 Guidelines (IPCC, 2006). It is a comprehensive guideline for GHG inventories at the national level. However, it can also be applied at city level as it has been the first method ever adapted for city-level inventories (Lombardi, Laiola, Tricase, & Rana, 2017). As a supporting fact, the principles, approaches, and methodologies provided by the IPCC Guidelines are adopted and applied by all urban GHG inventory frameworks that are mentioned under Section 1.3, namely the IEAP, BEI, ISC, PAS 2070 and GPC. The IPCC Guidelines consist of five sectors covered by five volumes as listed below:

Volume 1 General Guidance and Reporting (GGR) (applicable to all sectors)

Volume 2 Energy

Volume 3 Industrial Processes and Product Use (IPPU)

Volume 4 Agriculture, Forestry and Other Land Use (AFOLU)

Volume 5 Waste

Each sector includes individual categories (e.g. transport) and sub-categories (e.g. trains); and eventually a national total is constructed from the summation of emissions and removals from these sub-categories. One should follow the specifications in *Volume 2: Energy* for the quantification of emissions from indoor residential heating by natural gas and electricity consumption.

Principles and Implementation

The IPCC Guidelines are originally proposed to be used by countries that prepare their GHG inventories and report to the UNFCCC. They provide guidance on assuring quality on all steps from data collection to reporting. The principles followed by the guidelines are defined as the indicators of inventory quality and can be listed as *consistency, comparability, completeness, accuracy and transparency* (IPCC, 2006).

Scope of the Inventory

The IPCC Guidelines covers the emissions of six Kyoto gases as well as nitrogen trifluoride (NF_3), trifluoromethyl sulphur pentafluoride (SF_5CF_3), halogenated ethers and other halocarbons not covered by the Montreal Protocol. IPCC also identifies GWPs for the GHGs covered to be converted into CO_2e (IPCC, 2006).

System Boundary

As per the IPCC Guidelines, national inventories should include emissions and removals occurring within national territory and offshore areas over which the country has jurisdiction. The Guidelines indicate that inventories should represent emissions and removals taking place in one calendar year. In case the suitable data is not available, estimations should be made based on other years by means of appropriate methods such as averaging, interpolation or extrapolation. The Guidelines also underline the significance of tracking emissions trends over time and state that countries should establish a sequence of annual GHG inventories (IPCC, 2006).

Data

The IPCC Guidelines is the source of the “Tier approach”, which represents the varying levels of methodological complexity. Three tiers are defined under this approach, namely: “Tier 1” as the basic method, “Tier 2” as intermediate and “Tier 3” as the most demanding in terms of complexity and data requirements. Within this scope, readily available national or global statistics and provided default emission factors, which can be used by the Tier 1 method, are called “default data” (IPCC, 2006).

Emissions Scopes

The WRI definitions of emissions scopes are not recognized by the IPCC Guidelines. As per the classification of emissions in the IPCC Guidelines, emissions from indoor residential heating is listed under stationary consumption with the code and name *“1A4b – Residential”* and described as *“all emissions from fuel combustion in households”*. Since the guidelines are originally intended for national GHG emissions quantification, residential electricity consumption is not directly referred to. However, emissions due to electricity generation is listed under stationary consumption with the code and name *“1A1ai – Electricity Generation”* and described as *“emissions from all fuel use for electricity generation from main activity producers except those from combined heat and power plants”* (IPCC, 2006)

Calculation

The IPCC Guidelines requires the emission factor-based accounting methodology for quantifying most emissions, and thus the emissions are calculated according to Equation (1). This basic equation can be modified if needed, to account for other parameters than EFs. For the calculation of emissions from stationary sources, methods of Tier 1, 2 and 3 approaches are presented individually in Chapter 2 of Volume 2, which are summarized in Table 2-4.

Table 2-4. Summary of Tier 1, 2 and 3 Methods for Stationary (adapted from the IPCC Guidelines)

Sector	Tier	Activity Data	Emission Factors
Stationary Combustion	1	Amount of fuel combusted in the source category	A default emission factor
	2	Amount of fuel combusted in the source category	A country-specific emission factor for the source category and fuel for each gas
	3	Amount of fuel combusted per type of technology (i.e. the combustion device, process or fuel property that might affect the emissions)	Emission factor by fuel and technology type

Although the IPCC Guidelines state that using a Tier 3 approach is generally deemed needless since CO_2 emissions is independent from the combustion technology, plant-specific data is becoming increasingly available around the world due to the interest in emissions trading (IPCC, 2006).

The guidelines also specify uncertainty assessment as an important constituent of good practice for national inventory development and provide a detailed guidance on how to perform an uncertainty assessment. Through this assessment, the range and likelihood of possible values for the inventory as a whole and for its components (i.e. the emission factors, activity data and other parameters, if any) are determined. Uncertainty assessment is deemed crucial for identifying the categories that contribute most to the overall uncertainty and prioritizing future inventory improvements accordingly. As another measure against reducing uncertainties and improving the inventory quality, the guidelines strongly recommend regular communication and consultation with providers of data at all stages from data collection to reporting (IPCC, 2006).

1.3.7 Academic Literature Findings for Urban CF Accounting

The academic community has also been active in developing urban CF accounting methodologies since 2008 (Lombardi, Laiola, Tricase, & Rana, 2017). In 2008, Ramaswami et al. developed a demand-centered, hybrid and life-cycle based methodology for establishing urban GHG inventories, which was applied to Denver, Colorado. Through this methodology, the indirect emissions associated with the embodied energy of key urban materials production (e.g. food, water, fuel and concrete) and surface and airline transportation were included in the inventorying process in addition to the direct emissions. As Ramaswami et al. state, prior to this study, these additional sectors appeared in personal, national and global GHG emission calculations but not in city-scale inventories. Therefore, this inclusion was deemed important as it established consistency of inclusions across spatial scales. Applying the methodology, Denver's urban GHG emissions were calculated as 14.6 million tCO_2e in 2005, 14% of which occurred due to energy use in residential buildings. During the calculations, energy and water use were measured from local utility billing data, which were considered high-quality data. As per the residential energy use, electricity and natural gas use across all homes in Denver were obtained from the local energy utility and were benchmarked against similar data from other states and national studies for comparison purposes. Results of the computations for Denver showed that the developed methodology provided a more holistic estimation for the city's GHG inventory that coincided well with national and state-level per capita benchmarks. The researchers also indicate that this study can contribute to GHG mitigation policies related to the included airline travel and urban materials sectors that would otherwise be disregarded (Ramaswami, Hillman, Janson, Reiner, & Thomas, 2008). This methodology was then applied to eight US cities, results of which were found to be largely similar and consistent with the regional and national averages (Hillman & Ramaswami, 2010).

Ramaswami et al. developed and analyzed different approaches for urban CF accounting in 2011, which include *"purely geographic production-based accounting"*, *"geographic-plus (transboundary) infrastructure supply chain accounting"* and *"pure consumption-based accounting"* (Ramaswami, Chavez, Ewing-Thiel, & Reeve, 2011). The aim of developing these approaches was to allocate the in-boundary and trans-boundary GHG emissions to communities. The first approach accounts for all emissions occurring within the boundary of an entity and relates them to productivity metrics such as GHG per gross domestic product

(GDP). This approach is stated to be inappropriate for small cities where large carbon-intensive electricity inflows and inter-city commuter travel are observed. The second approach was developed to overcome this limitation; and addressed the inclusion of trans-boundary supply chains of cities by building on the CF accounting protocols established for corporations. As a result, the second approach was observed to yield an expanded infrastructure-based supply chain CF for a city, which is useful for future infrastructure planning. Finally, the third approach allocates trades of all goods and services across cities by primarily using the household consumption/expenditure data. To be more precise, the energy use in a residential building is not allocated to the city where the energy production facility is located, but to the households that purchase and use the energy service. Eventually, both the geographic-plus and consumption-based approaches were observed to deliver useful CF information to cities based on their typology (i.e. net-producing, net-consuming or trade balanced city) (Ramaswami, Chavez, Ewing-Thiel, & Reeve, 2011).

In 2012, the transboundary infrastructure supply chain method (TBIF) was applied to Delhi, India; which is a rapidly developing city with a large contribution to global CO_2 emissions. The results were compared to those of the cities in U.S. In the end, the TBIF method was found to be very useful for establishing a comprehensive CF for Delhi (Chavez, Ramaswami, Dwarakanath, Guru, & Kumar, 2012). In another study, the aforementioned three different approaches were compared based on three US cities. Mathematical relationships between the methods were analyzed along with their policy relevance. The study showed that there is not one method that results in a more holistic GHG emissions estimate for cities. Rather, the significance of knowing the city typology for choosing the right method to focus on was re-confirmed and emphasized. According to the results, TBIF yields a larger CF than does the consumption-based method for a net-producing city while the opposite applies for a net-consuming city, which also reveal whether the GHG mitigation activities should be focused on production or consumption activities. On the other hand, mitigation activities should be equally focused on consumption and production activities for trade-balanced large metropolitan cities (Chavez & Ramaswami, 2013).

A relatively simplified UCF accounting model was developed by Yajie et al. in 2014, which was named as the “Emission Sources Account (ESA)” model. The model followed the IPCC guidelines an analyzed four groups of emission sources only: energy consumption, soil and crop, livestock and solid waste. The researchers applied the model to the Dongguan city to calculate its CF between years 1990 and 2010 and concluded that the ESA model provided a common basis for UCF comparisons among cities and supported urban climate change mitigation policies (Yajie, Beicheng, & Weidong, 2014).

Lastly, in 2015, Lin et al. elaborated two new methods that intended to fill the gap in urban GHG emissions embodied in products traded among regions and intra-city sectors. The newly defined methods were therefore focused on the production activities; and were named as “production-based footprint (PBF)” and “purely production footprint (PPF)”. Using the trade information and urban input-output tables in their study, Lin et al. compared the UCF of Xiamen city for 2010 based on five accounting methods, three of which being the methods mentioned by Ramaswami et al. in 2011, and the other two being the PBF and PPF methods. Each of the five methods yielded different values and policy implications. As an active trading and net carbon exporter city, Xiamen City had higher trade-related embodied emissions than other production or consumption-related emissions; and thus, the UCFs based on the PBF and PPF methods totaled the highest. Accordingly, Lin et al. state that the production-based accounting methods can notify the producers to seek and take mitigation measures (Lin, Hu, Cui, Kang, & Ramaswami, 2015).

1.4 The Situation in Turkey: Urban GHG Inventories

International alliances are established around the world to bring together the forces of cities and local governments to reduce GHG emissions and climate risks. Brief information about the major ones together with the member municipalities and metropolitan municipalities (MMs) from Turkey are provided in Table 2-5 below:

Table 2-5. Information on International Organizations for Local Governments' Coalition

<table>
<tr><th>Name of the Alliance</th><th>Founding Date</th><th>Launched by/at</th><th>Approximate number of members</th><th>Members/Signatories from Turkey</th><th>Reference</th></tr>
<tr><td>ICLEI – Local Governments for Sustainability</td><td>1990</td><td>Launched by more than 200 local governments from 43 countries convened at the World Congress of Local Governments for a Sustainable Future in New York</td><td>More than 1,500 cities, towns and regions</td><td>• Bursa MM
• City of Gaziantep
• Kadikoy Municipality
• Kartal District Municipality
• Konya MM,
• Seferihisar Municipality
• Sisli Municipality</td><td>(ICLEI, n.d.)</td></tr>
<tr><td>C40 Cities Climate Leadership Group</td><td>2005</td><td>Launched by Ken Livingstone (Mayor of London)</td><td>More than 90 megacities</td><td>• Istanbul</td><td>(C40 Cities, 2018)</td></tr>
<tr><td>EU Covenant of Mayors</td><td>2008</td><td>Launched by the European Commission</td><td rowspan="3">7,755 signatories in 53 countries</td><td rowspan="3">• Antalya MM
• Bagcilar Municipality
• Bayindir Municipality
• Bornova Municipality
• Bursa MM
• Cankaya Municipality
• Eskisehir Tepebasi Mun.
• Gaziantep MM
• Istanbul MM
• Izmir MM
• Kadikoy Municipality
• Karsiyaka Municipality
• Maltepe Municipality
• Nilufer Municipality
• Pendik Municipality
• Seferihisar Municipality
• Sisli Municipality</td><td>(Covenant of Mayors, n.d.).</td></tr>
<tr><td>Compact of Mayors</td><td>2014</td><td>Launched at the UN Climate Summit</td><td>(Compact of Mayors, 2016)</td></tr>
<tr><td>Global Covenant of Mayors (CoM) for Climate & Energy</td><td>2016</td><td>In June 2016, the EU Covenant of Mayors joined forces with the Compact of Mayors, and together they created the "Global Covenant of Mayors for Climate and Energy"</td><td>(Covenant of Mayors, n.d.)</td></tr>
</table>

In line with the above-mentioned global steps being taken to combat climate change and its effects, cities and local governments make commitments to join the alliances and they measure and report on their GHG emissions as an “action plan” to monitor their progress towards the emission reduction targets. Within this scope, several municipalities and metropolitan municipalities from Turkey has been, and still is, developing their action plans and measuring their GHG emissions since 2011 (Covenant of Mayors, n.d.). Seventeen action plans from Turkey were identified, which have been completed at the time of the writing of this thesis. These action plans are in the form of a *Climate Change Action Plan (CCAP), Sustainable Energy Action Plan (SEAP),* or *Sustainable Energy and Climate Action Plan (SECAP).* Brief information on these seventeen action plans are provided in Table 2-6 below, with the emphasis placed on residential CFs and identified data-related issues. It should be noted that the urban CF figures in the table represent urban/district scale emissions excluding municipal corporate emissions.

Table 2-6. Brief Information on Action Plans Established in Turkey

Name & Date of the Action Plan	**Prepared for/under**	**Followed Methodology(ies)**	**Inventory Year**	**Residential CF ($ktCO_2e$)**			**Urban CF ($ktCO_2e$)**	**Per capita Residential CF (tCO_2e)**	**Identified Data Gaps/Limitations**
				Scope 1/ Direct [a]	**Scope 2/ Indirect [b]**	**Total**			
Gaziantep Preliminary CCAP (Internation Conseil Energie, 2011)	Gaziantep MM	Bilan Carbone® Methodology of ADEME	2007	890	480	1370	4560	1.05	Data inadequacies on average energy consumption by industrial branches
Karsiyaka SEAP (Karsiyaka Municipality, 2012)	EU Covenant of Mayors	N/A	2009	N/A	N/A	371.00	589.59	N/A	N/A
Kadikoy District Municipality SEAP (Kadikoy Municipality, 2013)	EU Covenant of Mayors	IEAP	2010	502.21*	291.61*	803.25	1620.04	1.53*	Data were more difficult to obtain at the district scale than at the corporate scale; and were provided from external stakeholders (e.g. Istanbul MM) by official means.
Bornova Municipality SEAP (RA Alternatif Enerji , 2013)	EU Covenant of Mayors	IEAP	2011	N/A	N/A	228.96	1015.58	0.55*	Authority issues and resistance may be encountered during data provision from external stakeholders and institutions

Table 2-6. Brief Information on Action Plans Established in Turkey (continued)

Antalya MM SEAP (Demir Enerji Danismanlik, 2013)	EU Covenant of Mayors	The Corporate Standard for municipal CF (UCF methodology not indicated)	2012	115.48	1119.93	1235.41	8821.98	N/A	Data inadequacies on amounts and disposal methods of wastes from agriculture and forestry activities
Seferihisar District Municipality SEAP (Seferihisar Municipality, 2013)	EU Covenant of Mayors	IPCC	2012	1.94*	11.01*	13.36	60.46	0.43*	During data acquisition from non-municipal institutions (e.g. electricity and natural gas distribution companies), problems regarding data quality and elaboration were observed due to inadequate human resource capacity.
Eskisehir Tepebasi Municipality SEAP (Eskisehir Tepebasi Municipality, 2014)	EU Covenant of Mayors	IEAP, IPCC Guidelines, BEI	2010	174.94	75.53	250.47	864.07	N/A	Data obtained from official authorities were either city-based or city center-based. No specific data for only Tepebasi Municipality existed. Thus, the data obtained were adjusted based on population.

Table 2-6. Brief Information on Action Plans Established in Turkey (continued)

Mugla Province 2013 GHG Inventory and SEAP (Aydın, Sabuncu, Demirkol, Cansever, & Büke, 2015)	EU Covenant of Mayors	GPC	2013	134.53	380.19	514.72	11,203.77	0.59*	- Since data on fuel consumed for heating purposes could not be obtained for Commercial and Institutional Buildings, only Scope 2 emissions due to electricity consumption were calculated. - Data on coal consumption in industrial plants could not be obtained. - Since fuel oil consumption data of individual sectors could not be obtained, the total amount sold was assumed to be consumed in residential buildings.
Pendik District CF Study (Pendik Municipality)	Pendik Municipality	IPCC	2014	259.77	175.35	436.54	7092.92	0.66*	N/A

Table 2-6. Brief Information on Action Plans Established in Turkey (continued)

Bursa MM Corporate and Urban CF Inventory and SEAP (Bursa Metropolitan Municipality, 2015)	Bursa MM	IPCC Guidelines	2014	1735.75	876.85	2612.60	12,825.15	0.94*	- Scope 3 emissions from the fuel consumption of waste collection vehicles were not included due to data inadequacy - Emissions from water transport were not included due to lack of data - Authority issues and resistance may be encountered during data acquisition. Energy consumption data, in particular, can only be retrieved through inter-institutional relations due to confidentiality issues that emerged after energy distribution privatizations. - Fuel-oil consumption was only accounted under industrial sector since consumption distribution data was not found.

Table 2-6. Brief Information on Action Plans Established in Turkey (continued)

Bursa Nilufer District Municipality SEAP (Ruzgar Danismanlik, 2016)	EU Covenant of Mayors	IPCC Guidelines, BEI	2013	N/A	N/A	356.71	737.63	0.99*	N/A
Maltepe Municipality SEAP (Demir Enerji, 2016)	Global Covenant of Mayors (CoM)	IEAP, IPCC Guidelines	2014	304.29	173.07	477.36	1408.54	0.98*	During data acquisition from non-municipal institutions, problems regarding data quality and elaboration were encountered due to inadequate human resource capacity.
Izmir MM SEAP (İzmir MM Environmental Protection and Control Department , 2016)	EU Covenant of Mayors	IPCC Guidelines, IEAP	2014	891.40	1834.11	2725.51	21,451.53	0.66*	No reliable electricity consumption data could be obtained from the electricity distribution company after the privatization in 2014; therefore 2012 data were considered.
Energy-Related CF Inventory of Bilecik City Centre (Türe, 2016)	Bilecik Municipality	IEAP, IPCC Guidelines, BEI	2015	30.23	17.43	47.66	577.23	0.64*	Difficulties can be faced in achieving detailed data on energy consumption.

Table 2-6. Brief Information on Action Plans Established in Turkey (continued)

Cankaya Municipality SEAP (Cankaya Municipality External Relations Department, 2017)	EU Covenant of Mayors	IEAP, IPCC Guidelines, BEI	2015	619.77	252.10	871.87	3713.36	0.95*	Data obtained from official authorities were either city-based or city center-based. No specific data for only Cankaya Municipality were found. Thus, the data obtained were adjusted based on population.
Bayindir District Urban GHG Inventory Analysis (Bayindir Municipality, 2017)	Global Covenant of Mayors (CoM)	IEAP, IPCC Guidelines, BEI	2016	N/A	13.88	N/A	383.61	N/A	Difficulties can be faced in achieving and compiling detailed data on actual energy consumption.
Bursa SECAP (Bursa Metropolitan Municipality, 2017)	EU Covenant of Mayors	IPCC Guidelines	2016	2124.93	885.28	3010.21	14,148.60	1.04*	There is no committee to investigate the impact of climate change on public health, and there is no data platform for institutions, universities and NGOs to share their data.

[a] Scope1/Direct residential emissions refer to those resulting from fuel combustion
[b] Scope 2/Indirect residential emissions refer to those resulting from the consumption of grid-supplied energy
* Not directly stated; but calculated by using the population figures or by the percentage distribution of emission sources given in the same document.

It is also worth mentioning that Pendik District CF Study covers the emissions for 2012, 2013 and 2014; yet only the 2014 figures are presented in the above table since they are the most recent ones. Furthermore, Bursa SECAP (2017) is the revised version of Bursa MM Corporate and Urban CF Inventory and SEAP (2015); and has been prepared in line with the decision taken by CoM after COP 21 Paris meeting, which mandates local governments to prepare a Sustainable Energy and Climate Change Adaptation Plan (SECAP) along with SEAP. With its SECAP, Bursa has been the first city to develop climate change adaptation strategies in Turkey (Bursa Metropolitan Municipality, 2017). Bursa SECAP revises the 2014 emissions covered by the 2015 SEAP and calculates the urban CF for 2015 and 2016. Again, only 2016 figures are provided in Table 2-6 as they are the most recent ones. As can be seen, the residential CF of Bursa was calculated as 2612.60 ktCO_2e for 2014 in the 2015 SEAP, which was revised in Bursa SECAP as 2959.04 ktCO_2e. The difference between two figures is due to the updated emission factors used in SECAP, as well as the updated residential natural gas consumption figures. According to Bursa SECAP, there was no significant change in residential CF in 2015 and it was calculated as 2837.39 ktCO_2e. However, it significantly increased by around 6% to 3010.21 ktCO_2e in 2016, which is mainly linked to the increase in industrial electricity consumption (Bursa Metropolitan Municipality, 2017).

Table 2-6 also indicates that difficulties are often encountered during the data acquisition process, the most common of which can be listed as sub-city level (i.e. district level) data inadequacies, data quality and elaboration problems due to inadequate human resource capacity and difficulties in achieving reliable electricity consumption data due to confidentiality issues occurred after the privatization in 2014.

1.5 The Role of GIS in CF Accounting: Former Studies

Geographic Information Systems (GIS) can simply be defined as a computer system for capturing, storing, analyzing and displaying data identified according to geographical location (USGS, n.d.). GIS gathers and organizes layers of information into visualizations by using maps and 3D scenes; and thanks to this feature, it contributes to smarter decision-making by providing deeper insight into data patterns and relationships (ESRI, n.d.).

The field of GIS field first started in 1960s with the emergence of computers and early concepts of quantitative and computational geography. In the same years, research has been done on spatial analysis and visualization concepts, which provided the basis for GIS. The first computerized GIS was developed in 1963 by Roger Tomlinson and was named as “Canada Geographic Information System”. Subsequently, the Harvard Laboratory for Computer Graphics was established in 1965, in which many early GIS applications were conducted by various talented scientists. In 1969, one of the members of the Harvard Lab, Jack Dangermond, and his wife Laura established Environmental Systems Research Institute, Inc. (ESRI). As a consulting firm, ESRI showed the contribution of GIS to informed decision-making and set the current standards to GIS. In 1981, ESRI started to improve its software tools and GIS became commercial (ESRI, n.d.). Today, GIS has become a useful means for data sharing and collaboration in various fields from education to sustainability, including CF accounting studies. Examples from the literature to the utilization of GIS and its functions in CF accounting studies will be presented in this chapter.

GIS has been proven to serve as a decision-making tool for identifying suitable locations to establish renewable and bioenergy power plants. Several former GIS-based studies have been conducted to facilitate smarter decision-making for determining the optimal location(s) for biomass power plants by also considering the costs and environmental impacts of biomass supply chains. Delivand et al. determined the biomass spatial availability, logistics costs and corresponding life-cycle GHG emissions of alternative scenarios for appropriate locations of prospective biomass power plants in Southern Italy, by using an integrated approach of GIS and multi-criteria analysis (MCA) (Delivand, Cammerino, Garofalo, & Monteleone, 2015). Similarly, Zhang et al. focused on developing a decision support system to determine the optimal location for biofuel facilities that minimizes the overall cost, including the energy consumption and GHG emissions, by using a combined approach of GIS data and simulation/optimization models (Zhang, et al., 2016) (Zhang, Wang, Liu, Zhang, & Sutherland, 2017). In one of the most recent studies, Sánchez-García et al. performed a GIS-based analysis to determine the optimal location of a hypothetical wood-fired power plant in Northern Spain. By using ArcGIS (i.e. the GIS software developed by ESRI), not only the physical and legal availability of the woodfuel to be used was analyzed; but also, the costs and GHG emissions of the supply chain for a specific demand point were calculated based on the LCA approach. The individual GHG emissions from six phases involved in the supply chain were calculated by using the IPCC baseline model; and the trucking phase was identified as the major contributor to overall GHG emissions (Sánchez-García, et al., 2017).

GIS-based quantification of GHG emissions from biomass burning activities has also been studied by researchers. Prasad et al. used GIS in combination with remote sensing and ground-based measurements, to quantify the GHG emissions occurring due to slash and burn agricultural practices in the forests of Eastern Ghats of India. In the study, data on land use was transferred into GIS platform; and emissions were calculated at a spatial scale by using ARC-VIEW GIS (Prasad, Badarinath, & Gupta, 2002).

Efforts have been made by researchers for developing a standardized, GIS-based approach for quantifying GHG emissions resulting from the electrical energy consumption of municipal water and wastewater services. In a study conducted by Bakhshi and deMonsabert, the GHG emissions associated with the energy consumption of water and wastewater needs of Fairfax County was estimated based on two different models incorporated into GIS platform. One approach estimated the energy consumptions through hydraulic equations and the other used the actual electrical consumption data. By comparing the two approaches, the authors concluded that metered consumption data is preferred over the hydraulic calculations for a better estimation (Bakhshi & deMonsabert, 2009). In another study, Bakhshi and deMonsabert have estimated the GHG impact of the municipal water life cycle in Loudoun County, Virginia; based on the LCA approach and by making use of ArcGIS. The researchers used GIS in their study mainly due to the dependence of embodied energy on the service area topography. Their proposed model combined the annual electricity consumption data, customer water demand, customer locations and an accurate GIS database. The study demonstrated the feasibility of using GIS for such purposes and provided resultant GIS output maps for customer water demand and associated GHG emissions (Bakhshi & de Monsabert, 2012).

Researchers have studied on GIS-based estimation of land use-related GHG emissions as well. While many scholars have studied the calculation of land use related GHG emissions from different aspects, Zhang et al. have proposed a GIS-based method for the estimation of emissions due to comprehensive land use, which includes both the natural and anthropogenic emissions sources. Using various types of data such as vegetation carbon data, soil organic carbon data, socio-economic data and land use data of 1980s, 1995 and 2010, Zhang et al. estimated the comprehensive land use related GHG emissions of Henan Province, China for 2010. ArcGIS software was utilized in the study during the extraction of land use maps of the area (Zhang, Tan, Huang, Lai, & Chuai, 2013). In another former study conducted by Yao et al., uncertainties in the estimates of methane (CH_4) emissions from Chinese rice paddies were aimed to be reduced by coupling field-scale emission models to regional GIS databases. ArcGIS software was used in the study for the creation and analysis of spatial databases. As a result of the study, estimation of CH_4 emissions from rice paddies by using the proposed methodology could be made; however, the need for further studies was emphasized to quantify the estimation uncertainties and enhance the quality of regional datasets (Yao, Wen, Xunhua, Shenghui, & Yongqiang, 2006).

Dalvi et al. have developed a GIS-based method to provide surface emission data in gridded form, which is required by most of the atmospheric chemistry models; yet is often inaccessible. Focusing on carbon monoxide (CO) emissions in India, Dalvi et al. firstly downscaled the emissions inventory of a broader level, such as state level, to finely gridded values that represent district level. Finally, the data was gridded into the finest resolution through mapping in GIS and by using local data. The study also demonstrated the individual contributions of various emission sources to the overall inventory (Dalvi, et al., 2006).

GIS is also used to provide an input emission inventory in Regional Air Quality Models (RAQM). In their study, Puliafito et al. proposed a method to develop an emissions inventory for the transport sector with high resolution to overcome the low spatial resolution issues observed in international databases. The readily available information on vehicle activity, fuel consumption and fuel efficiency were distributed to a spatial grid by using GIS; and an emissions inventory was prepared for the transport sector in Argentina. Puliafito et al. state in their paper that the resultant inventory performs better in terms of spatial distribution of GHG emissions than the international databases (Puliafito, Allende, Pinto, & Castesana, 2015). Kuonen has also studied on the GIS-based estimation of travel-related GHG emissions. In the study, the GHG emissions from the travel activities of participants from many countries to the European Geography Association (EGEA) Annual Congress held in Wasilkow, Poland, was estimated; and the emission reduction potentials were assessed. European emission means of different transportation means were used as the emission factors, and the travel distances were calculated based on open-source geographical data integrated into ArcGIS. The results demonstrated successful estimation of emissions and analyses of emission reduction scenarios (Kuonen, 2015).

Scholars have also utilized GIS in former studies for spatial CF accounting, which is closer to the objective of this thesis. Kuzyk developed a methodology to estimate the ecological and carbon footprints at a city, town or village scale by establishing a correlation between the consumption and income data and incorporating it into GIS. With this study conducted based on the data of Calgary, Canada; not only the correlation between income, consumption and sustainability was confirmed, but also a comparison basis for local sustainability levels among areas was provided (Kuzyk, 2011). Hua et al. estimated the CF of the farmland ecosystem in Hunan

Province, China, based on the statistics data of crop production between 2000-2010; and demonstrated the spatial and temporal variations in CF by using GIS (Hua, Xionghui, Qingbo, & Jia, 2012).

Asdrubali et al. have developed a GIS-based method for municipal CF accounting in Spoleto, Italy, to deliver an innovative and facilitative tool for local decision-makers by geo-referencing all identifiable carbon sources and sinks. Asdrubali et al. have aimed to estimate the contributions of different sectors to GHG emissions at the municipal level, as well as enabling the simulation of the GHG impacts of planned actions. The developed methodology has used emission factors from the literature data and accounted for activity data with two different accuracy levels, namely primary and secondary input data. The territory has been divided into two representative groups as the "industrial area" and the "residential area" for initial testing of the tool, in both of which residential buildings exited. Only primary input data have been available for residential sector in both areas, which included the mean heat/electricity consumption value per building typology as well as physical characteristics of buildings (e.g. construction year, intended use, number of floors, area, etc.). Within the tool, all the GHG sources and sinks have been geo-referenced and the outcomes are visualized in the "raster data" format, which lays a grid over the land. Therefore, the total CF value has been expressed in "tCO_2/ha" (Asdrubali, Presciutti, & Scrucca, 2013). Similar to the study conducted in this thesis, actual building data were used, and emission densities were spatially analyzed by Asdrubali et al. However, mean consumption data per building type were used and total emission densities were discussed by Asdrubali et al. while actual consumption data were used and densities of residential total and per capita CF values were also discussed in this thesis.

In another study, Aydin et al. used a GIS-supported air pollution module within the GHG emissions inventory of Muğla Province, Turkey, and demonstrated the air pollution due to coal combustion for residential heating purposes. Gaussian distribution models established for air pollutants in Muğla city center have been integrated into GIS for visualization. In the same study, energy modeling studies were conducted based on building typologies in Muğla, and their annual energy consumptions per m^2 have been estimated. These estimations based on building types have then been extrapolated to city level by utilizing GIS software, and the GHG emissions of the city center have been estimated based on general assumptions (Aydın, Sabuncu, Demirkol, Cansever, & Büke, 2015). Visualization through GIS was in common the study conducted in this thesis. However, air pollution and energy modelling was the main purpose and estimated energy consumption data for different building types were used by Aydin et al. while actual consumption data were used in this thesis.

In a quite recent study, Fagbeja et al. utilized GIS to construct an emission inventory infrastructure for the Niger Delta region of Nigeria. To overcome the disadvantages of data inadequacies and limitations arising from being a developing country, Fagbeja et al. developed an inventory infrastructure by using publicly available and accessible government and literature data. Using a bottom-up estimation approach, three kinds of activities were accounted for as emission sources, one of which is residential cooking and lighting using biofuels and fossil fuels. Other two activities are stated as industrial stationary combustion and road transportation. Emission estimation was conducted by inputting the details of emission sources in Microsoft Excel spreadsheet, and the results were linked to GIS by using the "spatial attributes" function of ArcGIS. With this inter-operability of spreadsheets and GIS; spatial analysis, mapping and visualization of the inventory infrastructure were conducted. The inventory consisted of point, line and area-source emissions; and residential sources were defined as the only area-source. For estimating the emissions from residential sources, a series of derivations had to be made, including the derivation of population estimates for settlements and number of households within individual settlements. The population derivation had to be made since official population data in Nigeria is not available at community/settlement level. Settlements were then categorized into "urban", "semi-urban" and "rural" communities based on their population and size; and the number of households within each settlement was then estimated based on additional assumptions. Most appropriate emission factors were determined as well as the average period for cooking and lighting activities; and the quantification was then made base on these assumptions and by using the most general, emission factor-based equation. Fagbeja et al. state that residential emission estimation has uncertainties due to various reasons, including the unverifiable settlement population, incomplete settlement database, generalized input data, out-of-date and general emission factors and assumptions made to produce most activity data. In the end, Fagbeja et al. concluded that the constructed inventory infrastructure still had a high-level of uncertainty due to various assumptions made because of data adequacy and accuracy issues. However, the study validated the functionality of the developed infrastructure and its potential contribution to the identification of data gaps and construction of better quality inventories as accurate and sufficient data become available (Fagbeja, et al., 2017).

Similar to the study conducted in this thesis, the purpose was to overcome the disadvantages of data inadequacies and limitations, and mapping and visualization was done through GIS. However, residential heating was not taken into account, population derivation was made due to lack of verifiable settlement population data and actual building and consumption data were not used by Asdrubali et al. while residential heating was accounted for, verifiable household population figures were taken and actual building and consumption data were used in this thesis.

CHAPTER 3

METHODOLOGY OF THE RESEARCH

The aim of this research is to develop a GIS-based CF accounting methodology for residential buildings based on their actual electricity and natural gas consumption figures in a pilot area to minimize the limitations caused by deficiencies in CF-related data generation and access; and to contribute to local policy-making by providing useful tools and results to decision-makers. Within this scope, three types of residential heating systems that predominate in Turkey were focused on, namely:

- individual heating (IH) systems that are used for standalone heating,
- central heating (CH) systems that are used for block-based heating, and
- district heating (DH) systems that are used for neighborhood-based heating.

Along with its main purpose, this study was also intended to be a partial continuation of an earlier study conducted by Evren in 2015, in which the natural gas consumption levels, energy efficiencies and CO_2 emissions of the above-mentioned three residential heating systems were compared (Evren, 2015). This study complements the previous one not also by utilizing a GIS software and database, but also by taking into account the electricity consumption of sample buildings in addition to their natural gas consumption. By doing so, a more comprehensive residential CF calculation is enabled.

The city for the case study was chosen as Bursa, which is the same as the previous study. With its population recorded as 2,936,803 in 2017, Bursa is the fourth most populous city of Turkey (TUIK, 2017). Also, the average number of households per residential building is 2.69 in Bursa, which is above the average in Turkey (2.38) (Bursa Metropolitan Municipality, 2015). Considering these two facts, residential sector is expected to significantly contribute to the overall urban CF in Bursa. The figures from the 2014 urban GHG inventory of Bursa supports this assumption since emissions from the residential sector (Scope 1 and Scope 2 combined) were shown to constitute 20.73% of total emissions (Bursa Metropolitan Municipality, 2015).

All sample buildings to be studied in this research were initially selected as the same buildings from the previous study, which was then had to be modified due to the reasons explained in the following sections. Brief information on the initially selected sample buildings are presented in Table 3-1 below.

Table 3-1. Information about the initially selected sample buildings

Residential Heating System	Name	Address	Additional Information
DH	Saygınkent Complex	Yüzüncüyıl Neighborhood, Prof. Dr. Erdal İnönü Street, Nilüfer Municipality, Bursa	- Built in 2005 - Consists of 7 standard-shaped, 18-storey blocks with 476 dwelling units in total - Has a heating center which feeds the 7 residential blocks - Connected to a DH system that feeds over 25 blocks and 750 dwelling units (Evren, 2015)
CH	Mescioğlu Foreli Evler-4 Complex (C-Block)	23 Nisan Neighborhood, 257th Street No. 12, Nilüfer Municipality, Bursa	- Built in 2012 - C-block is an 8-storey building with 30 dwelling units - The Complex consists of 3 identical blocks in total
IH	Yidem Apartment	Cumhuriyet Neighborhood, Anıt Street No. 18, Nilüfer Municipality, Bursa	- Built in 2000 - A 5-storey apartment building with 15 dwelling units

2.1 Initial Research and Preliminary Data Collection

The previous study used the natural gas consumption data of the sample buildings for the year 2014 (Evren, 2015). However, to better calculate the residential CFs of the sample buildings, natural gas and electricity consumption figures for the years

2014-2017 were needed. The main reasons for selecting a four-years period rather than one year were to:

i) eliminate any errors that may have occurred in a certain period within a year due to misreading of electricity/natural gas meters etc.,
ii) see the fluctuations in the consumption figures throughout a longer period, and
iii) achieve a more reliable CF result.

During the preliminary research, it was found out that natural gas consumption data are recorded on the database of Bursagaz (i.e. the natural gas distribution company in Bursa) based on the address information of customers; however, this was not the case for electricity consumption data. The electricity consumption data are recorded on the database of the distribution company in the region (namely "Uludağ Elektrik Dağıtım A.Ş. (UEDAŞ)"), based on the electricity meter serial numbers/subscriber numbers of customers rather than their address information. Which means, the address information of the initially selected could not be used for obtaining their electricity consumption data; and serial numbers of their electricity meters were needed.

In addition, a GIS database of the selected neighborhoods (i.e. Yüzüncüyıl, Altınşehir and Cumhuriyet Neighborhoods) and a few adjacent neighborhoods were needed since the purpose of this study is to calculate the residential CF of a larger pilot area based on the unit area consumption figures of the sample buildings. Therefore, a GIS database with the following features of the buildings in the region were searched for:

- building type (i.e. residential, commercial, etc.)
- roof and/or floor area,
- number of floors, and
- type of the residential heating system.

In order to obtain such GIS database, Bursa Metropolitan Municipality (MM) and Nilüfer Municipality were contacted. Although Bursa MM provided a GIS database that include data such as boundaries of the neighborhoods s within Nilüfer, and the Nilüfer Municipality provided some numerating information via e-mail, adequate and up-to-date GIS database required by this study could not be obtained during the preliminary research.

Consequently, a field visit was planned to see the sample buildings on site, collect the required information about the electricity meters, obtain the natural gas and electricity consumption data, and find an adequate GIS database.

2.2 Fieldwork and Data Collection

The field visit was held on Friday, February 23, 2018. Firstly, a visit to the DH type building, Saygınkent Complex (hereinafter will be referred to as "Saygınkent"), was made and authorized personnel of the site administration were contacted. In Saygınkent, there was an individual electricity meter for each dwelling unit within a block, and the electricity meters were located at the doors of the dwelling units. The electricity meters of the common areas within C-block (such as the elevators) and whole Saygınkent (such as the pool, parking garage, etc.) were also maintained in C-block. Since the complex had 476 dwelling units in total, photographing each and every electricity meter would be extremely impractical and time-consuming. Therefore, it was decided to use only the consumption data of C-block for sake of simplification. With the guidance of the technical staff, electricity meters of 71 dwelling units in C-block; and the two common electricity meters were photographed. Exterior view of C-block and a sample electricity meter can be seen in Figure 3-1.

Figure 3-1. Exterior view of Saygınkent C-block and a sample electricity meter respectively

Right after Saygınkent, the CH-type building, Mescioğlu Foreli Evler-4 Complex (hereinafter will be referred to as "Foreli-4"), C-block was visited. In this building, the electricity meters of all dwelling units were kept in a small room; hence, the meters of 30 dwelling units and two common electricity meters were easily photographed. Exterior view of Foreli-4, C-block and a sample electricity meter can be seen in Figure 3-2 below:

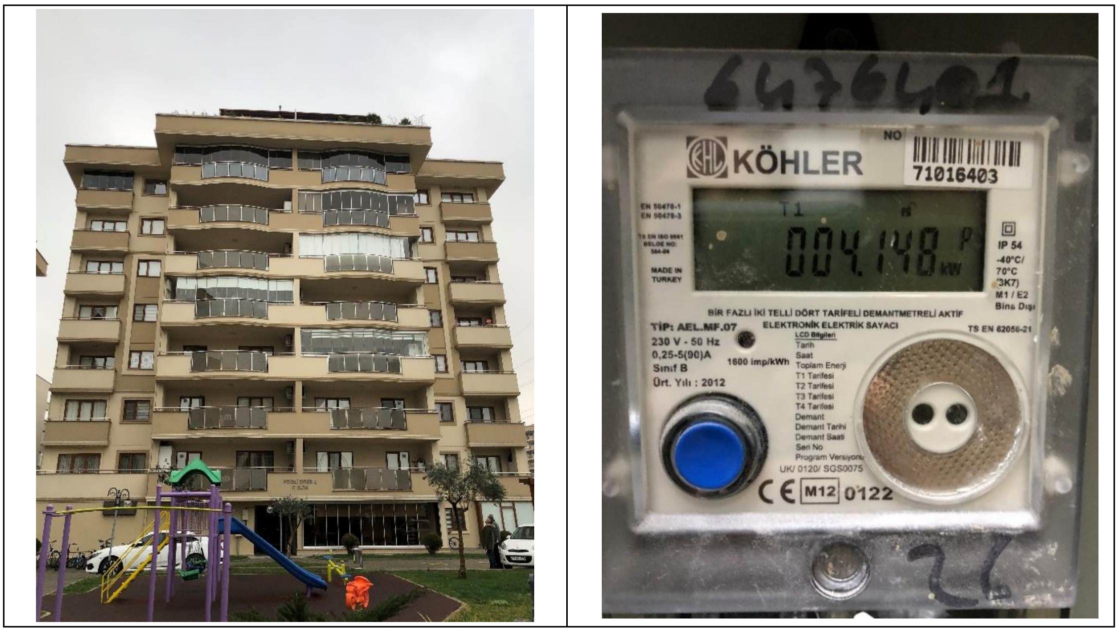


Figure 3-2. Exterior view of Foreli-4 C-block and a sample electricity meter respectively

Subsequently, the initially selected IH building, Yidem Apartment was visited. However, the building was demolished due to urban transformation and a new building was built in its place. Since the construction of the new building was completed quite recently, it had no residents. Exterior view of the old building, Yidem Apartment, and that of the newly built apartment are provided in Figure 3-3.

Figure 3-3. Exterior view of the old Yidem Apartment (Evren, 2015) and the new building respectively

As there were no residents in the new building, it would not be possible to obtain any electricity or natural gas consumption data. Therefore, a new IH-type sample building with similar features had to be found. As a result, a new IH-type, 6-storey building with 25 dwelling units (1 being the housekeeper's dwelling unit) was found in Altınşehir Neighborhood. The IH-type sample building is named as Bakgör-2 Life Houses (hereinafter will be referred to as "Bakgör-2"), B-Block. Electricity meters of 25 dwelling units and the common electricity meter of the building were photographed. A sample meter from Bakgör-2, B-Block is shown along with the exterior view of the building in Figure 3-4.

Figure 3-4. Exterior view of Bakgör-2 B-Block and a sample electricity meter

2.2.1 Collection of the Electricity Consumption Data from UEDAŞ

After visits to the sample buildings were completed, UEDAŞ was visited to contact the authorized personnel and to receive briefing on how to reach the electricity consumption data of the sample buildings. According to the information received, consumption data were recorded on UEDAŞ database based on the serial numbers located right below the barcode on the meters. Therefore; the electricity consumption data of each electricity meter photographed in the DH-, CH- and IH-type sample buildings were requested via the serial numbers. The kWh-based electricity consumption data were received on a monthly basis for the years 2014-2017 on an Excel spreadsheet. The obtained electricity consumption data was then organized to be used for CF calculations.

2.2.2 Collection of the Natural Gas Consumption Data and GIS Database from Bursagaz

As the last stop of the field visit, Bursagaz was visited to request the natural gas consumption data of the selected sample buildings. As a private distribution company, Bursagaz complies with the requirements of *"Natural Gas Market Tariff Regulation"* by the Energy Market Regulatory Authority (EMRA) while billing the natural gas consumption amounts of its customers. Accordingly, Bursagaz records the natural gas consumption amount both energy-based (as kWh) and volume-based (as Sm^3). As per the Regulation, Sm^3 stands for "standard cubic meters", and refers to the amount of natural gas that does not contain water vapor and that has an upper calorific value of 9155 kcal, filling a volume of 1 m^3 at a temperature of 15 °C and an absolute pressure of 1.01325 bar) (EMRA, 2016). The unit "Sm^3" is used for the standardization of gas volume based on its calorific value, which is required since the energy generated from the combustion of natural gas is dependent on its chemical content (Evren, 2015).

Since Bursagaz records the natural gas consumption data based on the address information of their customers, the addresses of the DH, CH and IH-type sample buildings were sufficient to request the natural gas consumption data of each dwelling unit within. Consequently, the Sm^3-based natural gas consumption data were received on a monthly basis for the years 2014-2017 on an Excel spreadsheet. The obtained gas consumption data was then organized to be used for CF calculations. It should be noted that although Bursagaz reads the gas meters monthly, the consumption data is not recorded for amounts less than 20 Sm^3 (Evren, 2015). This can be observed on the natural gas consumption data of IH-type buildings in summer when natural gas is not consumed for residential heating purposes; and the consumption amounts occur as "0" in July and August.

During the visit to Bursagaz, it was also seen that Bursagaz has a comprehensive and up-to-date GIS database of the city. On this database, the buildings were drawn as polygons on a shapefile based on their actual floor areas; which enabled the calculation of residential building area in this study.

As in the case of Yidem Apartment, many buildings in Cumhuriyet Neighborhood and its surroundings have been undergoing urban transformation, which was also approved by Bursagaz personnel. Therefore, using the GIS database of this region for this study would be misleading. After eliminating the villages and focusing on dense residential areas, a total of six adjacent neighborhoods were selected to study on; and their GIS database were provided by Bursagaz. The selected neighborhoods were namely *19 Mayıs Neighborhood*, *Yüzüncüyıl Neighborhood*, *29 Ekim Neighborhood*, *Altınşehir Neighborhood*, *Ertuğrul Neighborhood* and *23 Nisan Neighborhood*. The area of study and the boundaries of six selected neighborhoods are shown in the map provided in Figure 3-5 below.

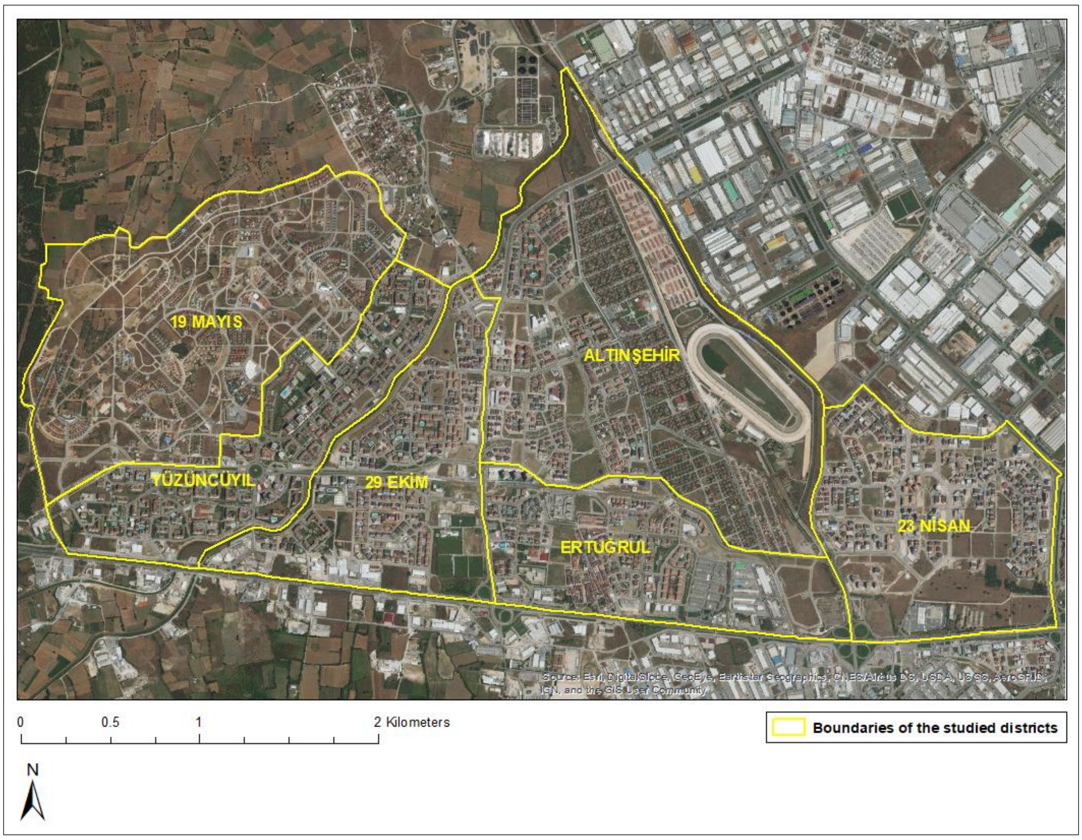


Figure 3-5. Boundaries of the Six Selected Neighborhoods

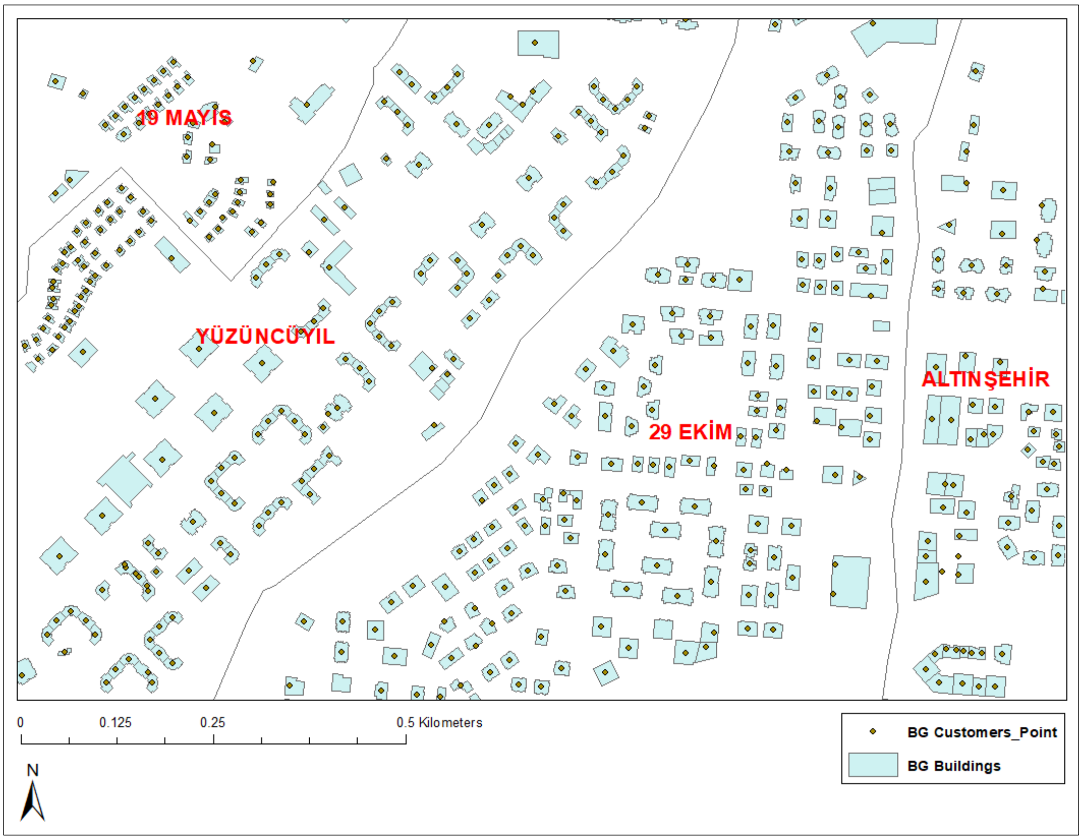
2.3 Organization and Completion of the GIS Database

Although Bursagaz's GIS database was quite comprehensive and up-to-date, and contained valuable data in the first place, it still lacked certain information required for this study and had to be further modified to be completed.

In this section, first, brief information about the initial GIS database is provided in Section 2.3.1 and then the corrections, assumptions and auxiliary tools used for the completion of the database are detailed in Section 2.3.2. finally, outcomes of the initial GIS database analyses are provided in Section 2.3.3.

2.3.1 Initial GIS Database at a Glance

After the field visit and data collection, GIS database provided by Bursagaz was further analyzed by using the ArcMap software, which is the main component of ArcGIS developed by Esri to create maps, perform spatial analyses and manage geographic data (Esri, 2018). The obtained GIS database mainly consisted of two layers (shapefiles): i) customer points, which is a point-type shapefile that contains information about Bursagaz's customers; and ii) buildings, which consists of polygons drawn based on the actual floor areas of buildings (including both Bursagaz customers and non-customers). It should be noted that the neighborhood names and boundaries were obtained from the GIS database shared by Bursa MM; and were merged with Bursagaz's GIS database. Figure 3-6 below presents a section from ArcMap where both layers are shown to provide better understanding. As can be seen, each customer point is linked to a customer building, which are demonstrated as polygons.



**BG stands for "Bursagaz"*

Figure 3-6. Demonstration of the shapefiles obtained from Bursagaz GIS Database

The buildings shapefile mainly contained the polygons based on actual floor areas. Some polygons in the database were triangular; which were, as stated by Bursagaz personnel, new Bursagaz customers whose actual floor areas have not yet been reflected to the GIS database.

In the customer point shapefile, a customer point was assigned to each customer building, which contained data of 4294 customer buildings initially, including their:

- address information,
- type of the residential heating system, and
- number of dwelling units and work places found within.

2.3.2 Corrections, Assumptions and Auxiliary Tools

Corrections, assumptions and auxiliary tools used for the completion of the GIS database are listed and explained below, in the order of implementation:

i. Control of the Customer Point Data with 0 or 1 Dwelling Units

The initial database contained information on the number of dwelling units and work places found within the customer buildings. However, one thing that attracted attention was that the dwelling unit number of 2732 out of 4294 customer point data (i.e. almost 2/3 of the whole) was defined as either “0” or “1”. A separate layer of these 2732 customer points was created (See Figure 3-7) and converted into a KMZ file (i.e. a placemark file used by Google Earth) to check the related data one-by-one by using the “Street View” tool of Google Earth. Thus, the most accurate and up-to-date information about the buildings was sought via real-world imagery provided by Street View (see Figure 3-8 for an example).

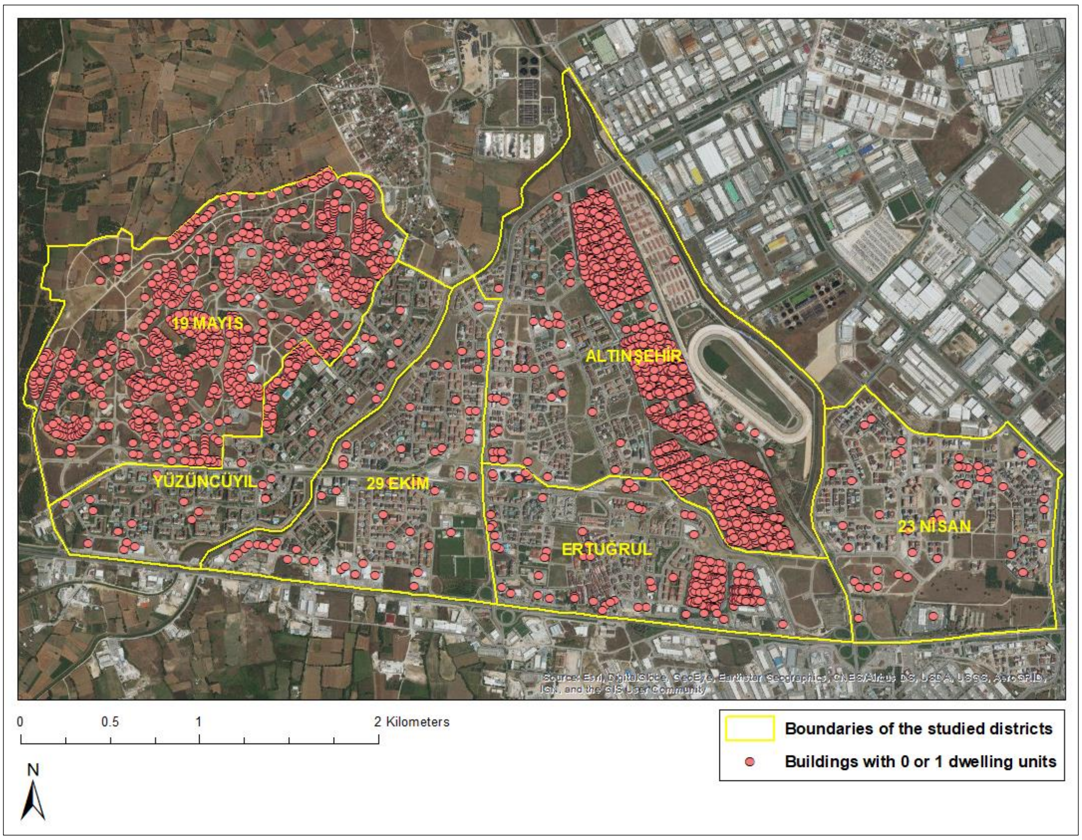


Figure 3-7. Customer buildings with 0 or 1 Dwelling Units

(Source: Google Earth)

Figure 3-8. An Imagery from the Area of Study on the Street View

As a result, it was found out that most of these 2732 customer points were single houses. In total, 2251 customer buildings were identified as single houses; and they were denoted as “SH” in the GIS database.

Some of the remaining buildings were not single houses, but rather were identified as public buildings used for commercial, educational or business purposes. For other buildings which could not be specified by using only Street View, Google Maps was also utilized as an auxiliary database completion tool. Information regarding buildings such as kindergartens, study centers or work places were collected from Google Maps where necessary; and was double-checked from the related company’s web site to make sure if it is their current address. The customer points that could not be identified by any of the auxiliary tools mentioned were marked and left as an “error” to be checked again later.

ii. Distinction Between Residential and Non-residential Buildings

The initial GIS database did not contain any information regarding the purpose of use of buildings (i.e. if the building is residential, commercial, etc.). Since the scope of this study covers only residential emissions, identification of the residential buildings in the area of study had to be made for an accurate calculation.

For this reason, the residential buildings were denoted as “E” and the non-residential buildings were denoted as “”H” in the GIS database. Accordingly, the identified single houses in the first step were marked as “E” and other identified public, non-residential buildings were marked as “H” in the GIS database. This process also continued to be held in the following steps, until the database was completed.

Some mixed-used buildings were also identified, where there were stores at the ground floor. Such buildings were generally considered as residential buildings if their ground floor area was identical to upper floor areas, since their consumption patterns were assumed not to be quite different from the building’s average. More detailed information about the corrections and assumptions made for such buildings is provided in subsection v. under this Section.

iii. Addition of Floor Number Information and Completion of the Remaining Customer Point Data

The most crucial data required for CF calculation were the number of floors in buildings and their floor area, along with the electricity and natural gas consumption figures. The floor area of the customer buildings was easily obtained in ArcMap by using the field calculator and calculating the polygon area of each customer point. However, the initial GIS database did not include the floor number information; therefore, it was manually added to the database for each customer point one by-one, based on the following approach:

- *For single houses*, number of floors were primarily added based on their Street View imagery. In cases where Street View imagery did not exist for the related customer point (which generally occur when the construction date of the building was later than the Street View imagery date), number of floors was assumed to be equal to the surrounding, similar-looking single houses, if any. If there were no surrounding buildings to take as a base, number of floors was assumed as “2”.

- *For apartment-type buildings*, number of floors of each customer point was primarily added based on their Street View imagery. In cases where their Street View imagery did not exist, number of floors was assumed based on the total dwelling unit number information of the building. It should be noted that the accuracy of this assumption was also tested and approved by checking from the dwelling unit numbers of customer points whose number of floors could be directly reached by using Street View. Accordingly:
    - for buildings with floor area greater than or equal to 500 m^2, the number of floors was calculated based on the assumption that each floor has 4 dwelling units,
    - for buildings with floor area between 400-500 m^2, the number of floors was calculated based on the assumption that each floor has 3 dwelling units, and
    - for buildings with floor area smaller than 400 m^2, the number of floors was calculated based on the assumption that each floor has 2 dwelling units.

Although efforts have been made to complete the floor number information as accurate as possible, there may have been some under or overestimations due to unusual architectural structures or unseen basement floors. For example, the building shown in Figure 3-9 has non-uniform floor area in every floor due to its architectural structure; therefore, calculation of the exact area for such rare cases could not be possible within the scope of this study.

(Source: Google Earth)

Figure 3-9. An Example Building with Non-Uniform Floor Area

The remaining 1584 customer point data with more than one dwelling units (See Figure 3-10) were also converted into a KMZ file; and each of them were checked by using Street View to see if they were residential or non-residential; and were defined accordingly on the GIS database. Also, the floor number information of these customer point data was completed by following the above-mentioned approach.

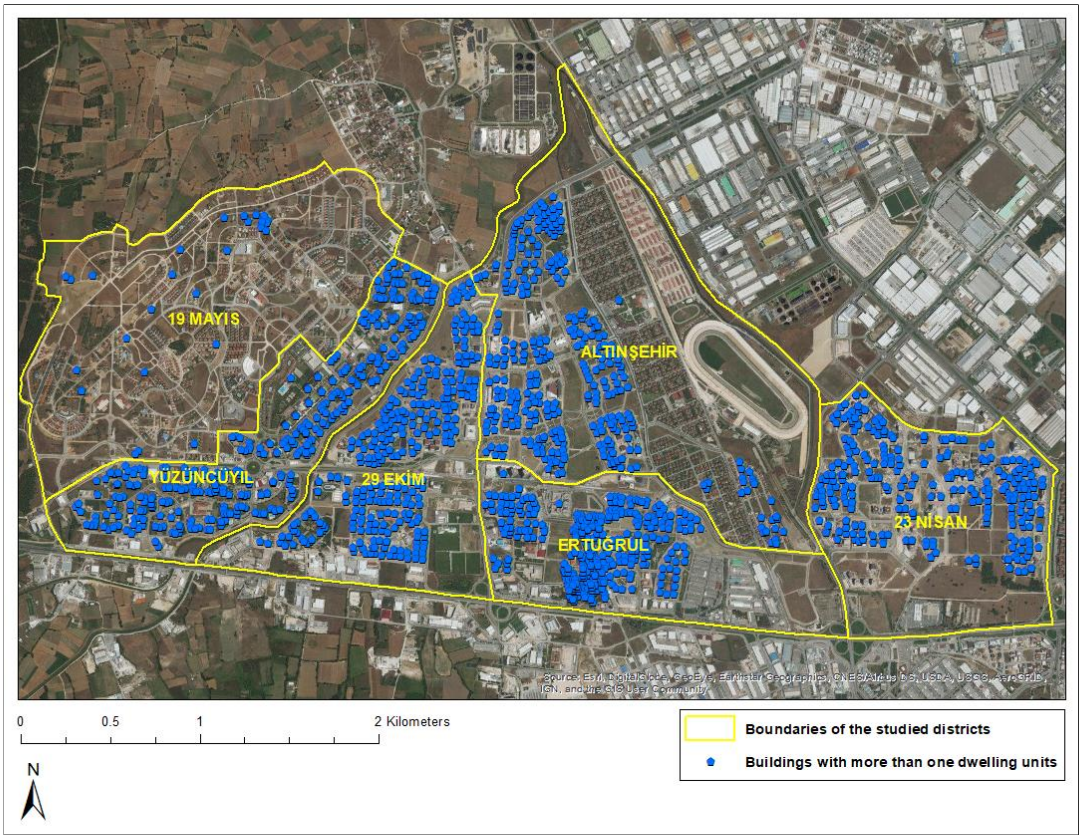


Figure 3-10. Customer Buildings with more than one Dwelling Units

iv. Adjustment of Excess and Missing Customer Points

The initial GIS database included some excess customer point data. Specifically, more than one customer point data were linked to the same polygon (i.e. customer building), an example of which is demonstrated in Figure 3-11. Since keeping more than one customer point data within a single polygon would lead to double-counting and corresponding overestimations of emissions, excess customer point data were removed from the database.

Figure 3-11. An Example to Excess Customer Point Data

On the other hand, some customer point data were missing in the initial database, especially in CH or DH-type building complexes. An example to such case is demonstrated in Figure 3-12. This may be due to the fact that a single heating center serves multiple blocks or the whole complex. However, since all blocks in a complex should be considered in an accurate area calculation, customer points were assigned to blocks where necessary. Accordingly, 29 new customer point data were added to the GIS database to avoid under-estimation of emissions, and the total number of customer point data increased to 4323 from 4294.

Figure 3-12. An Example to Missing Customer Point Data

There were some cases where polygons of some blocks in building complexes were also missing, which was recognized after a basemap (i.e. world imagery) was added as a layer to ArcMap. A new polygon was added for the missing blocks either by duplicating the existing blocks' polygons or by drawing a new one via the basemap.

After analyzing all of the customer point data, the ones whose purpose of use or number of floors could not be identified (which were only 16 in number) were classified as "non-residential" on the GIS database to be excluded from residential CF calculation.

v. Polygon Shape Corrections

On the initial database, most customer buildings were already drawn by Bursagaz as polygons based on their actual floor areas. However, shape corrections had to be made on the polygons of some customer buildings. During the organization and completion of GIS database, shape correction was applied to 122 polygons in total due to below listed reasons:

- As mentioned in Section 2.3.1, some polygons in the database were triangular; which were new Bursagaz customers whose actual floor areas have not yet been reflected to the database. By adding a basemap layer on ArcMap, shapes of triangular polygons were modified and brought closer to the actual floor area of related buildings based on their world imagery; although minor errors might have occurred due to angular deviations of the available basemap.
- Some buildings (especially residences) have a larger ground floor that are designed as stores or supermarkets. The polygons of such buildings were drawn according to these ground floors in the initial GIS database, which would lead to overestimation in area calculation. Such polygon shapes were corrected based on only the residential area of the building (i.e. by excluding the excess area of ground floors) via basemap. Figure 3-13 below demonstrates a 2-block residence with stores at their larger ground floor. The block on the left has a corrected polygon shape while the block on the right has an unmodified polygon shape based on the store area. It should also be noted that such stores were generally represented on the initial database by separate customer points, which were then marked as "non-residential" to be excluded from the calculations. On the other hand, stores at the ground floor of mixed-used apartments were considered as a part of the residential buildings if their ground floor area was identical to upper floor areas (an example is shown in Figure 3-14).

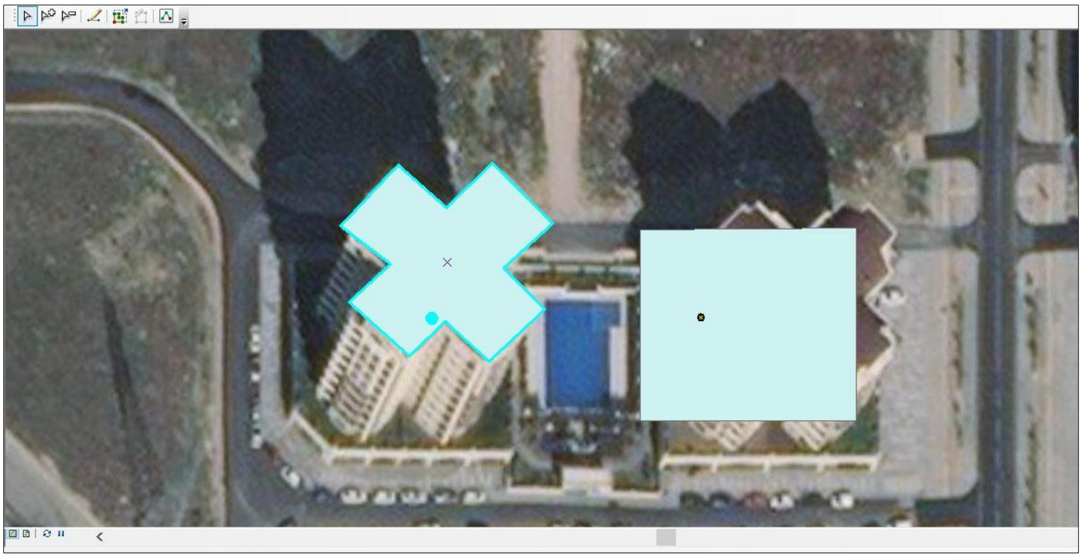


Figure 3-13. An Example Polygon Shape Correction

Figure 3-14. An Apartment with a Store Area Identical to Upper Floor Areas

- Finally, polygons that were noticeably small or large when compared to the basemap were corrected in order to minimize potential over- or underestimations.

vi. Identification of DH-type Customer Points

Initially, two types of residential heating systems were defined on Bursagaz's GIS database, which were "IH" and "CH". The DH-type customers were also recorded as "CH" on the system. Even though DH-type buildings have only 1% share among all residential customers of Bursagaz (Evren, 2015), they had to be defined as "DH" on the GIS database to for a proper calculation of residential CF in the area of study. This is mainly due to the fact that natural gas consumption patterns and values per unit area vary for IH, CH and DH-type buildings, which will be explained in detail in the following sections.

It was known from the previous study that 94% of Bursagaz's residential consumers were IH-type buildings, while CH had 5% and DH had 1% share, respectively (Evren, 2015). Considering this fact and that DH-type buildings are already included in the CH-type buildings on the database, it was calculated that CH and DH-type customers together formed 6% of all residential customers. Therefore, differentiation of DH-type customers was made based on the equation below:

$$\frac{DH}{(CH + DH)} = \frac{1\%}{(1\% + 5\%)} \cong 16\%$$

The final GIS database included 192 residential CH-type customer point data in total. Accordingly, 31 residential customer points were assigned as "DH" on the final database, which corresponded to almost 16% of residential CH-type customers. Among the assigned point data, 7 customer points were the blocks within Saygınkent, which were already known to be DH-type buildings from the former study. The remaining customer points were selected from big building complexes with 6 or more blocks by using basemap.

2.3.3 Outcomes of the Initial GIS Database Analyses

After all the corrections and modifications explained in the previous section were completed, the distribution figures and statistics shown in Table 3-2 and Table 3-3 below were obtained for the customer points.

Table 3-2. Distribution of the Customer Points in the final GIS database

Customer Point Type	Total Number of Point Data	Percentage (%)
Single House (Residential)	2251	59.1
Apartment-Type (Residential)	1556	40.9
Total Residential Customers	3807	88.1
Total Non-Residential Customers	516	11.9
Total Customers	**4323**	**100**

Table 3-3. Distribution of the Residential Heating Systems

Residential Heating System	Representation on the Database	Total Number of Point Data	Percentage (%)
Individual Heating (IH)	B	3615	95
Central Heating (CH)	M	161	4.2
District Heating (DH)	D	31	0.8
Total		3807	100

As the percentages in Table 3-3 indicate, the share of IH-type residential customers was slightly higher (by ≈1%) and those of CH and DH-type customers were slightly lower compared to the figures obtained from the previous study; however, the difference was negligible.

In order to better visualize the distribution of single houses and apartment-type buildings in the area of study, they are shown in the map presented in Figure 3-15 below. As can be seen, single houses are mostly located in 19 Mayıs and Altınşehir Neighborhoods. On the other hand, apartment-type buildings are found in every district although only a few of them are located in 19 Mayıs Neighborhood.

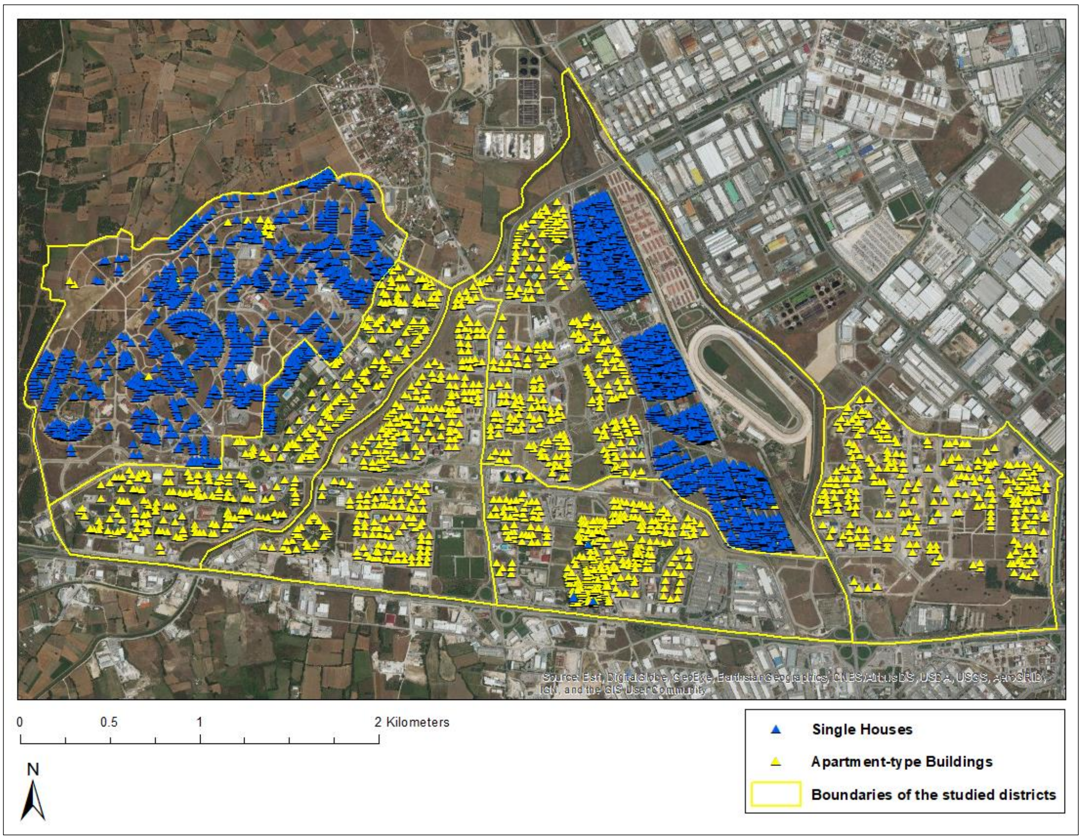


Figure 3-15. Distribution of Single Houses and Apartment-Type Buildings

After the completion of GIS database, a separate layer was created from only residential customer point data, on which the CF calculations were to be conducted. The "area" feature, which was previously calculated as "square meters" from the polygon areas on the buildings layer, was also merged with the related residential customer point data. As a result, all useful data was gathered in the attribute table of a single layer. The useful features gathered can be seen in the figure below, which is obtained directly from ArcMap.

Table

Residential_Buildings

FID	Shape *	KAPI_ID	BAGLI_BINA	MAHALLE_AD	CADDE_SOK	KAPI_NO	BINA_ISINM	SITE_ADI	TOPLAM_DAI	IS_YERI_SA	KAT_SAYISI	RESID	SH	Area_Final
1718	Point ZM	4202423	28758	ERTUĐRUL MH.	133.SK.	4/C	B	GÖRKEM EVL	2	0	3	E		164
1764	Point ZM	4134212	26446	ERTUĐRUL MH.	ERTUĐRUL S	46	B		2	1	3	E		143
1837	Point ZM	4159405	26281	ERTUĐRUL MH.	ELMAS SK.	37/1	B		2	1	3	E		110
1889	Point ZM	4159006	26294	ERTUĐRUL MH.	SAVCI DOĐA	47	B	GÖRKEM EVL	2	0	2	E		146
1964	Point ZM	4159009	25956	ERTUĐRUL MH.	SAVCI DOĐA	43	B	GÖRKEM EVL	2	0	2	E		147
1967	Point ZM	4159008	25959	ERTUĐRUL MH.	SAVCI DOĐA	45	B	GÖRKEM EVL	2	0	2	E		146
2436	Point ZM	4237403	254535	19 MAYIS MH.	YENÝBAHAR	17	B		2	0	4	E		194
3314	Point ZM	4305376	9927634	ALTINÞEHÝR MH.	205. SK.	12	B		2	0	2	E		89
3324	Point ZM	4304543	9927629	ALTINÞEHÝR MH.	204. SK.	22	B		2	0	3	E		142
3768	Point ZM	4328754	345717	ALTINÞEHÝR MH.	205. SK.	41	B		2	0	2	E		133
0	Point ZM	4224020	42256	19 MAYIS MH.	ORKÝDE SK.	2/C	B	VATAN SÝTE	1	0	2	E	SH	90
1	Point ZM	4225270	42024	19 MAYIS MH.	EGEMENLÝK	92/Y	B		1	0	2	E	SH	104
6	Point ZM	4228872	246020	19 MAYIS MH.	EGEMENLÝK	92/I	B	ATALAY 3 VÝ	1	0	2	E	SH	119
12	Point ZM	4223562	241017	19 MAYIS MH.	SELDA SK.	1/G	B		1	0	2	E	SH	101
13	Point ZM	4223564	241018	19 MAYIS MH.	SELDA SK.	1/F	B		1	0	2	E	SH	102
14	Point ZM	4226919	244240	19 MAYIS MH.	SÝDE CD.	29/C	B		1	0	2	E	SH	154
15	Point ZM	4225627	243049	ALTINÞEHÝR MH.	205. SK.	58	B		1	0	2	E	SH	73
29	Point ZM	4225760	42018	19 MAYIS MH.	AYÇÝÇEĐÝ S	24	B		1	0	2	E	SH	92

0 (0 out of 3807 Selected)

BG Customers_Point | Residential_Buildings | BG Buildings

Figure 3-16. Attribute Table of the Final Residential Buildings Layer

As can be seen in Figure 3-16, the final residential customers layer includes all necessary features for residential CF calculation, which are *residential heating system*, *floor area*, and *number of floors.*

2.4 Further Data Collection

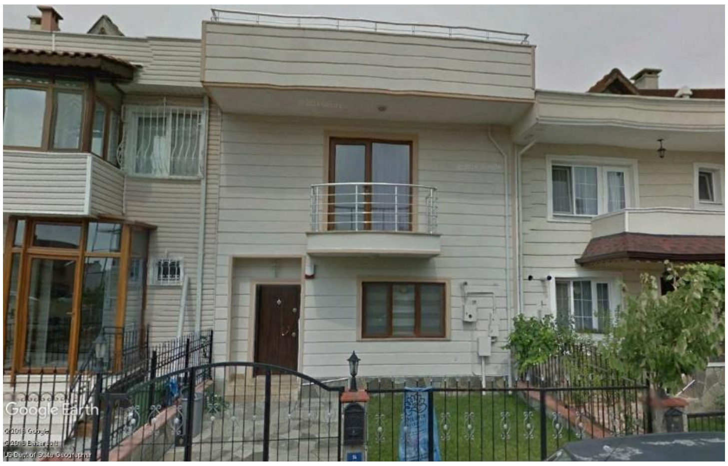
As stated in the previous section, it was realized during the initial analyses of GIS database that there was a substantial number of single houses in the studied area, which corresponded to 59.1% of all residential customer buildings. Although all of these single houses were IH-type, their residential electricity and natural gas consumption patterns were expected to be different than the apartment-type IH buildings. In order to achieve a more accurate CF calculation, sample buildings representing single houses had to be taken into consideration.

As can be seen in Figure 3-15, single houses are concentrated in two separate neighborhoods, namely Altınşehir and 19 Mayıs. The single houses in 19 Mayıs were observed to be relatively newer buildings while those in Altınşehir were relatively older. The houses in two neighborhoods also differed in size and luxury level (for example, there were a substantial number of houses with pool in 19 Mayıs). Considering these, working on sample buildings from both neighborhoods was thought to be the correct approach. Therefore, two sample single houses from Altınşehir and two sample single houses from 19 Mayıs were selected and the serial number information of their electricity meters were obtained. In line with the process applied for other sample buildings, the Sm^3-based natural gas consumption data and kWh-based electricity consumption data of sample single houses were collected from Bursagaz and UEDAŞ on a monthly basis for the years 2014-2017 on an Excel spreadsheet. For sake of simplicity, the sample single houses will be hereinafter referred to as "SH-1", "SH-2", "SH-3" and "SH-4". Detailed information of the samples is presented in Table 3-4.

Exterior views of sample single houses and their electricity meters can be seen in from Figure 3-17 to Figure 3-20 below:

(Source: Google Earth)

Figure 3-17. Exterior view of SH-1 and its electricity meter



(Source: Google Earth)

Figure 3-18. Exterior view of SH-2 and its electricity meter

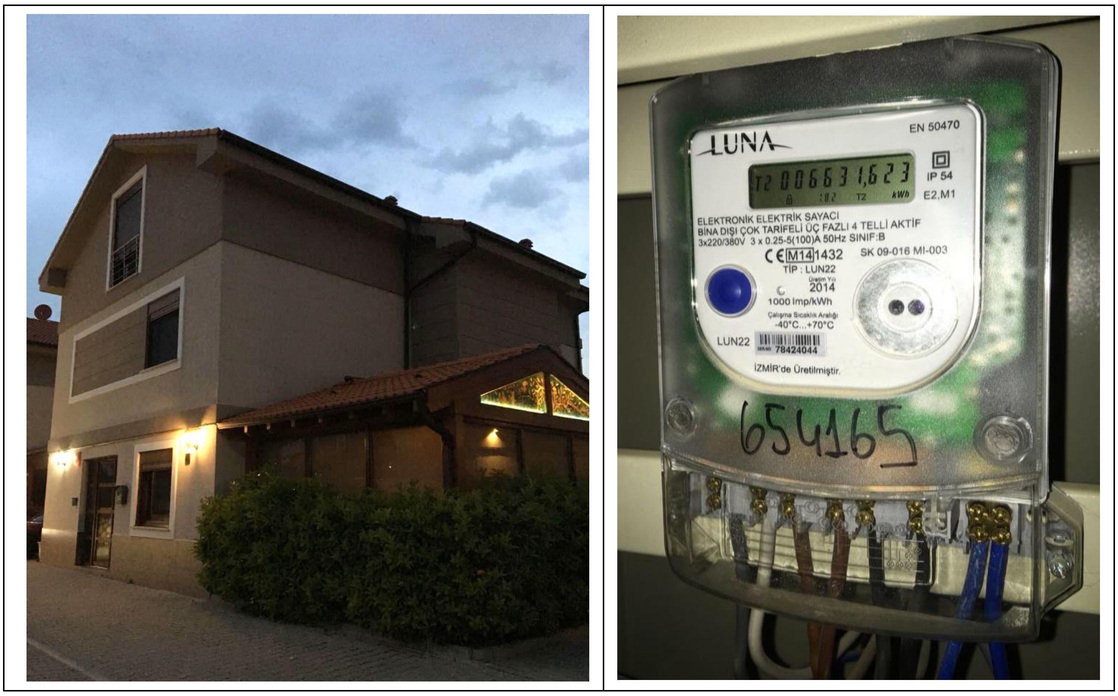


Figure 3-19. Exterior view of SH-3 and its electricity meter

Figure 3-20. Exterior view of SH-4 and its electricity meter

With the addition of these four new sample single house buildings, the final number of sample buildings used in this study increased to seven. Information on the final sample buildings are presented in Table 3-4; and a map on which all sample buildings are shown is presented in Figure 3-21.

Table 3-4. Information on the Final Sample Buildings

Residential Heating System	**Building Type**	**Name**	**Address**	**Additional Information**
DH	Apartment-type	"DH" (Saygınkent Complex, C-Block)	Yüzüncüyıl Neighborhood, Prof. Dr. Erdal İnönü Street, Nilüfer, Bursa	- Built in 2005 - Has a common heating center which feeds all complex - Connected to a DH system that feeds over 25 blocks and 750 dwelling units (Evren, 2015) - Calculated floor area: 1226 m^2
CH	Apartment-type	"CH" (Mescioğlu Foreli Evler-4 Complex, C-Block)	23 Nisan Neighborhood, 257th Street No. 12, Nilüfer, Bursa	- Built in 2012 - C-block is an 8-storey building with 30 dwelling units - Calculated floor area:
IH	Apartment-type	"IH" (Bakgör-2 Life Houses, B-Block)	Altınşehir Neighborhood, 312th Street No. 5/B, Nilüfer, Bursa	- A 6-storey apartment building with 25 dwelling units - Calculated floor area:
IH	Single House	"SH-1"	Altınşehir Neighborhood, 204th Street No. 21, Nilüfer, Bursa	- A 2-storey single house - Calculated floor area: 67 m^2
IH	Single House	"SH-2"	Altınşehir Neighborhood, 204th Street No.14, Nilüfer, Bursa	- A 2-storey single house - Calculated floor area: 70 m^2
IH	Single House	"SH-3"	19 Mayıs Neighborhood, Güllü Street, Manolya Villas No. 16/E, Villa 3/B, Nilüfer, Bursa	- A 3-storey single house - Calculated floor area: 102 m^2
IH	Single House	"SH-4"	19 Mayıs Neighborhood, Güllü Street, No. 21, Nilüfer, Bursa	- A 3-storey single house - Calculated floor area: 128 m^2

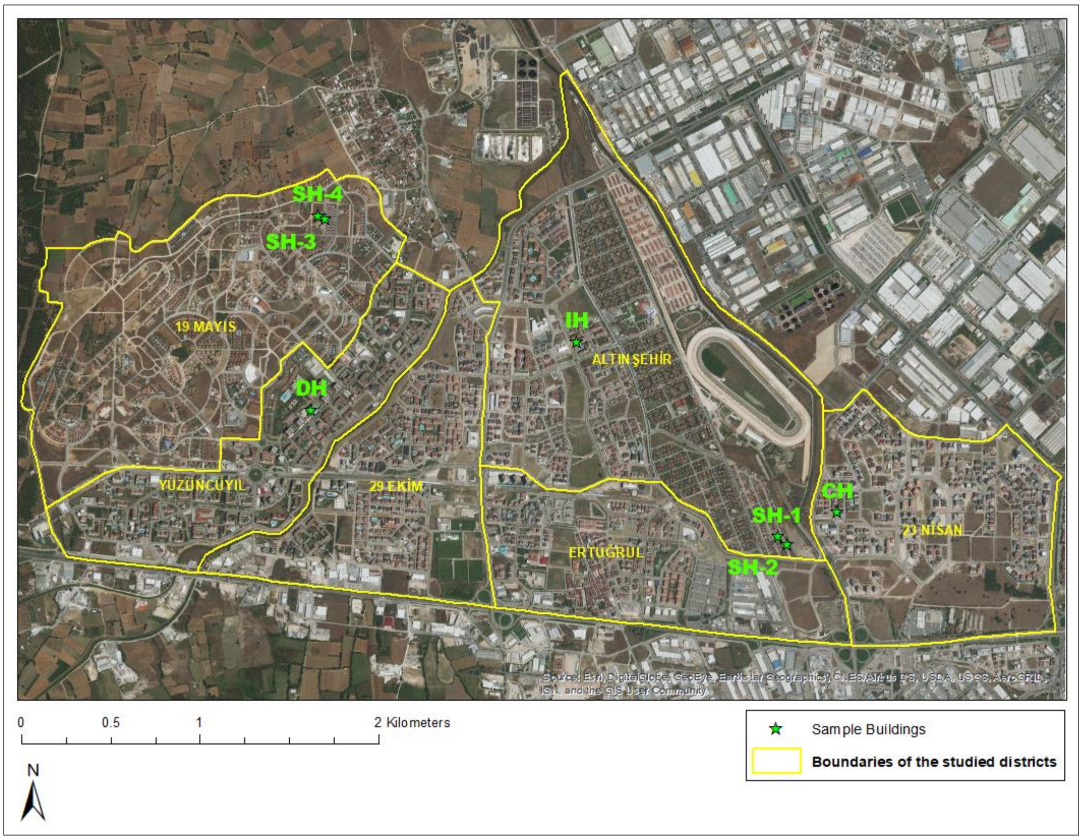


Figure 3-21. Locations of Final Sample Buildings

2.5 Background Information About the Area of Study and Sample Building Consumptions

After further data collection, the final area of study was determined and its general characteristics such as the number of IH-, CH-, DH- type residential heating systems and distribution of apartment-type and SH-type residential buildings within each of the 6 neighborhoods were examined. In addition, descriptive statistics of sample buildings' consumptions were obtained. Accordingly, the background information obtained are presented in this section.

Distribution of building types and heating system types within the area of study is presented in Table 3-5; and information about the floor areas and number of floors are provided in Table 3-6.

Table 3-5. Distribution of Building Types and Heating Systems

Neighborhood	Total number of residential buildings	Number of IH-type residential buildings	Number of CH-type residential buildings	Number of DH-type residential buildings	Number of SH-type residential buildings	Number of apartment-type residential buildings
19 Mayıs	985	985	0	0	969	16
Yüzüncüyıl	386	365	14	7	68	318
29 Ekim	292	255	25	12	0	292
Altınşehir	1524	1491	27	6	1210	314
Ertuğrul	344	328	10	6	4	340
23 Nisan	276	191	85	0	0	276

Table 3-6. Information on Floor Areas and Number of Floors

Neighborhood	Number of residential buildings by floor area			Average floor area of residential buildings (m^2)	Average number of floors in residential buildings
	< 400 m^2	400-500 m^2	≥ 500 m^2		
19 Mayıs	981	4	0	123.34	2.1
Yüzüncüyıl	349	7	30	286.42	7.7
29 Ekim	190	39	63	381.39	6.3
Altınşehir	1431	39	54	128.77	2.8
Ertuğrul	287	25	32	285.54	4.7
23 Nisan	169	40	67	403.67	8.0

As can be interpreted from the tables above, 19 Mayıs Neighborhood has the highest percentage of single houses while Altınşehir Neighborhood has the highest number of single houses within. Another interesting fact is that 23 Nisan Neighborhood has the lowest number of total residential buildings; but it has the highest average number of floors and also the largest average floor area. This is due to the fact that there are mostly relatively newer, multi-storey buildings in 23 Nisan instead of single-houses.

The collected 4-year data on electricity and natural gas consumption of sample buildings was examined; and the statistical information shown in Table 3-7 were obtained. It should be noted that the minimum consumption values are provided by excluding the null ("0") consumption values due to vacancy ratio or other factors.

Table 3-7. Consumption Statistics by Sample Building Types

Sample Building Type	**Electricity Consumption Statistics (kWh)**				
	Monthly Dwelling Unit Min.	**Monthly Dwelling Unit Max.**	**Monthly Dwelling Unit Average**	**Yearly Dwelling Unit Avg.**	**Yearly Building Average**
DH	0.07	3135.44	266.45	3197.45	366,845.77
CH	6.09	1180.87	166.64	1999.64	70,038.21
IH	2.12	537.67	195.26	2343.07	63,298.66
SH	79.94	1232.47	275.72	3274.15	3274.15
Sample Building Type	**Natural Gas Consumption Statistics (Sm^3)**				
	Monthly Dwelling Unit Min.	**Monthly Dwelling Unit Max.**	**Monthly Dwelling Unit Average**	**Yearly Dwelling Unit Avg.**	**Yearly Building Average**
DH	N/A*	N/A*	74,477.21 (whole complex)*	893,726.46 (whole complex)	
CH	N/A*	N/A*	2203.06 (whole building)*	26436.72 (whole building)	
IH	4.98	540.33	89.09	890.89	22,272.28
SH	10.86	716.33	152.33	1513.75	1513.75

**Dwelling unit-based consumption information is not available since consumption data is recorded based on a single heating center for the whole building/complex.*

It can be clearly seen that SH-type sample buildings have the highest monthly and yearly average electricity consumption and relatively higher natural gas consumption; even though one of the SH-type sample buildings did not have any consumption data for 2014 and 2015; and another did not have data for 2014. In order to better compare the consumption results of sample building types, their unit-area based consumptions should be taken into consideration, which are presented and explained in detail in Section 3.1.

2.6 Estimation of Residential Carbon Footprint in the Area of Study

After the fieldwork, data collection and completion of GIS database, calculation of residential CF in the area of study was started. In this study, the approach in the GPC Methodology, which is described in detail in Section 1.3.5, was followed for CF estimation. The main reasons for selecting GPC among other methodologies can be listed as follows:

- It is the most preferred, most recently established and most up-to-date accounting framework for urban GHG inventories globally.
- It was developed based on the previous experiences of former frameworks.
- It is a result of a joint effort by ICLEI, WRI and C40, with additional collaboration by the World Bank, UNEP, and UN-Habitat (ICLEI, n.d.).
- It offers a flexible system boundary approach ranging from a district to a metropolitan area depending on the purpose, which was deemed useful for this study since it aimed to calculate the residential CF in a pilot area of six neighborhoods.

As per the GPC, residential buildings sector is reported at the BASIC level since scope 1 and 2 emissions from stationary energy are covered by BASIC reporting, which requires a less-challenging data collection and calculation process. In this study, quality of activity data used can be classified as "High (H)" according to GPC classification (see Table 2-2) since actual consumption data were used. Moreover, the source for activity data in this study was "a representative sample set of real consumption data from surveys", which is the second most recommended source by GPC after "real consumption data for each fuel type, disaggregated by sub-sector" that requires monitoring at the point of fuel use or sale (WRI, C40 and ICLEI, 2014). On the other hand, use of high quality emission factors could not be possible for this study. This is due to the fact that the emission factors used were not specific emission factors since not much local emission factors exist in Turkey yet. For natural gas, the default emission factor provided by IPCC was used, which is therefore classified as a "Low (L)" quality data as per GPC. For electricity, Turkey's grid emission factor was used, which can be classified as "Medium (M)" quality data since it was country-specific rather than a default value.

The CF calculation was conducted for each year from 2014 to 2017, both years included. The calculations of each year were made under two scenarios, namely the *"minimum"* and *"maximum"* scenarios. The minimum scenario was based on the original consumption data, in which discontinuities existed in consumption data due to vacancy of some dwelling units. Although a certain vacancy ratio does exist in reality, a maximum scenario, in which the vacancy ratio is assumed as zero, was also implemented to be on the safe side and see the results of the case with 100% occupancy rate. Maximum scenarios were established by filling the null consumption data in the minimum scenarios by assuming them being equal to the average of the existing consumption data for each month.

As for the single houses, one of the sample buildings did not have any consumption data for 2014 and 2015 while one of them did not have data for 2014. The original data was again considered as the "minimum" scenario, in which it was assumed that the dwellers did not move in yet; while the "maximum" scenario was considered with 100% occupancy rate.

As a result, CF due to residential natural gas and electricity consumption; the sum of two, the total residential CF; and the per capita total residential CF were obtained for each sample building, for each year and for both "minimum" and "maximum" scenarios. Implementation of CF calculation is further explained in depth in Chapter 4.

2.7 Spatial Analyses of Emissions

As the last part of the methodology, a more in-depth analysis of the results of the residential CF calculations was performed through statistical and spatial analyses in Excel and ArcGIS. In addition to allowing for further discussions of results, this step was also intended to contribute to local policy-making by providing beneficial tools and outcomes to decision-makers. GIS was deemed as a powerful and beneficial tool to serve this purpose since the delivery of footprint calculations by visual images and maps from GIS help raise awareness, enable local policy-makers and community representatives to better communicate local and global actions; and consequently, support policy decision-making processes (Kuzyk, 2011).

Within this scope, analyses of $CF_{res,total}$, Per Capita $CF_{res,total}$, $CF_{res,NG}$, and $CF_{res,electricity}$ results for each scenario were performed. However, the results of the analyses for $CF_{res,NG}$ and $CF_{res,electricity}$ did not reveal a major difference; and these two parameters were eliminated from the analyses. Consequently, the purpose and methodology of the statistical and spatial analyses performed for $CF_{res,total}$ and Per Capita $CF_{res,total}$ are briefly described in this section in their application order. It should be noted that the results of the analyses mentioned in this section are provided in Section 3.4 together with their discussions.

2.7.1 Histogram Graphs

Histogram graphs are commonly used in statistics as an initial analysis to better interpret and visualize the frequency distribution of data, especially for rather large sets of data points, which was the case in this study. By creating a histogram graph from a dataset, source data values are grouped into value intervals called “bins”; and hence the overall distribution of the dataset is portrayed. In the histogram graphs, a bar is drawn for each bin, where its width (on the x-axis) denotes the value range of the bin, and its height (on the y-axis) denotes the number of data points that belong to that range (Esri, n.d.).

In order to understand the distribution of data, histogram graphs were created for $CF_{res,total}$ and Per Capita $CF_{res,total}$ for each scenario as the first step (see Section 3.4 for results).

2.7.2 Classification of the Emission Values

Various data classification methods are offered within ArcMap, which are used to classify the values within a dataset into ranges and visualize it on a map by using symbology. “Natural breaks (Jenks)” classification method is one of the commonly used methods, in which the classes are formed based on natural groupings inherent in the data. Class breaks are created in a way that the differences between classes are maximized and similar values are grouped the best (Esri, n.d.).

In this study, data values for $CF_{res,total}$ and Per Capita $CF_{res,total}$ for each scenario were classified by using the Natural Breaks (Jenks) classification method in ArcMap; and the emission data were grouped into five classes as *“very low”*, *“low”*, *“moderate”*, *“high”* and *“very high”*. Results of the classification are visualized on thematic maps, which are presented in Section 3.4.

2.7.3 Identification of the Statistically Significant Data Points

Identification of the statistically significant data points are performed in ArcMap by using the “Hot Spot Analysis (Getis-Ord Gi*)” spatial statistics tool. This tool is used for identifying the spatial clusters of high values (i.e. “hot spots”) and low values (i.e. “cold spots”) within a certain area. As a local statistics tool, hot spot analysis assesses each feature (the emission values in this case) at a local level, in the context of their neighboring features (Esri, n.d.). In other words, it provides a rather local cluster analysis and compares the local situation to global situation where all the available dataset is used (Esri, n.d.). Consequently, a thematic map is formed as the output of the tool, which demonstrates the spatial clustering of high values and low values in the area of study.

After a general classification of data using Natural Breaks method, hot spot analysis was performed for $CF_{res,total}$ and Per Capita $CF_{res,total}$ for each scenario to identify the statistically significant hot spots and cold spots. Hot spots and cold spots with 95% confidence level and above were taken into consideration. The thematic maps obtained by Natural Breaks classification and hot spot analysis were compared and the consistency between two maps was observed (see Section 3.4 for results).

2.7.4 Density Mapping

Density analysis is conducted to spread the known quantities of features (in this case, the emission values) across a certain area based on their measured quantities. Density mapping is used to visualize the results of density analysis. Accordingly, density maps demonstrate where the point features are concentrated and help better understand the spread of features across a certain area (Esri, n.d.).

In this study, density mapping of $CF_{res,total}$ and Per Capita $CF_{res,total}$ for each scenario were performed by using the "Kernel Density" tool in ArcMap. Kernel Density tool calculates a magnitude-per-unit area from point features; and produces a density map accordingly. The search radius (bandwidth) within which the density is calculated was taken as 300 m; and the population field was selected as the emission features of each data point. Kernel density maps are provided in Section 3.4 together with high/low clustering graphs that provide general statistical distribution of the maps. In addition, density maps of mean values (i.e. average of minimum & maximum scenarios) and coefficient of variation (COV) (i.e. *"the ratio of the standard deviation to the mean"*, which expresses the variability between minimum and maximum scenarios) of each year are provided. By doing so, it was aimed to better demonstrate the scale of difference between minimum and maximum scenarios through years and detect where the average values and COVs concentrate.

2.8 Limitations of the Study

Certain limitations were encountered during this study mainly because urban CF accounting is a technique that is yet to be standardized; and also due to the deficiencies in CF-related data generation and access, which were underlined in the outcomes of the action plans established in Turkey as well (see Table 2-6). The limitations can be listed as follows:

- In general, data required for CF accounting (e.g. fossil fuel consumption data) is rather simpler to obtain at the corporate-scale or country-scale.

However, it becomes more problematic to obtain data at smaller scales such as district-scale. This was also the case with this study since residential electricity and natural gas consumption data at district-level were not publicly available. Therefore, they had to be provided from external stakeholders (i.e. UEDAŞ and Bursagaz) by official means.

- A limited amount of representative sample buildings could be used for obtaining consumption data due to time limitation as well as community's privacy concerns and reluctance to data sharing.

- A default emission factor for natural gas consumption had to be used due to the lack of country or region-specific emission factor. Likewise, the national electricity grid emission factor for Turkey was used due to the lack of an emission factor specific to Nilüfer District or Bursa Province.

- Actual residential area data of buildings were neither publicly available nor it could be obtained from the GIS database used in this study. Consequently, floor areas of buildings were used; and accordingly, common area consumptions of the buildings (e.g. elevators, corridor lighting, etc.) were also taken into account alongside the dwelling unit consumptions to avoid underestimations.

- Although convenience of using a GIS software in CF accounting was observed to a certain extent, the initial GIS database lacked certain information required for this study and had to be further modified to obtain a complete GIS database that would serve the purpose of this study. The corrections and modifications made are explained in detail in CHAPTER 3.

- The average household population data for Bursa was used in this study for obtaining the Per Capita CF results due to the lack of household population data specific to district or building type.

Given the above-listed limitations of this study, recommendations for future studies are provided in Section 4.3.

CHAPTER 4

CALCULATIONS AND DISCUSSION OF THE RESULTS

In this study, total residential CF in the area of study was achieved based on Equation (2) below:

$$CF_{res,total} = CF_{res,NG} + CF_{res,electricity} \quad (2)$$

where:

$CF_{res,total}$ = Total residential carbon footprint (tCO_2),
$CF_{res,NG}$ = Carbon footprint due to residential natural gas consumption (tCO_2), and
$CF_{res,electricity}$ = Carbon footprint due to residential electricity consumption (tCO_2).

As briefly mentioned in Section 2.5, $CF_{res,total}$ of the area of study was calculated based on the monthly actual consumption figures of sample buildings for 2014, 2015, 2016 and 2017; and for minimum and maximum scenarios.

Calculations and discussion of the results were conducted in two main steps:

- **Step 1:** Calculation of the unit area (m^2) consumption for sample buildings based on real consumption data,
- **Step 2:** Calculation of $CF_{res,total}$ and Per Capita $CF_{res,total}$ of the area of study based on unit area consumptions obtained in Step 1, and
- **Step 3:** Discussion of the results based on spatial analyses of emissions.

In this chapter, details of Step 1 and Step 2 and their results are provided in Section 3.1 and Section 3.2, respectively. After the completion of Step 1 and Step 2, the results were compared and discussed in Section 3.3. The results of spatial analyses were then provided in Section 3.4; and then were further discussed in Section 3.5. Finally, different residential heating systems were compared based on their CFs in Section3.6.

3.1 Sample Building Consumptions per Unit Area

In order to obtain the $CF_{res,total}$ in the area of study, first, unit area-based electricity and natural gas consumptions of sample buildings representing DH-, CH-, IH-type buildings and single houses (SHs) were calculated according to Equation (3) and Equation (4) below:

$$E^*_{x,y} = \frac{E_{x,y}}{A_{F,x}\ x\ N_{F,x}} \tag{3}$$

where:

$E^*_{x,y}$ = Electricity consumption per unit area of sample building “x” in year “y” (kWh/m^2)

$E_{x,y}$ = Total electricity consumed by all dwelling units in sample building “x” in year “y” (kWh)

$A_{F,x}$ = Floor area of sample building “x” (m^2)

$N_{F,x}$ = Number of floors of sample building “x” (unitless)

$$NG^*_{x,y} = \frac{NG_{x,y}}{A_{F,x}\ x\ N_{F,x}} \tag{4}$$

where:

$NG^*_{x,y}$ = Natural gas consumption per unit area of sample building "x" in year "y" (Sm^3/m^2)

$NG_{x,y}$ = Total natural gas consumed by all dwelling units in sample building "x" in year "y" (Sm^3)

$A_{F,x}$ = Floor area of sample building "x" (m^2)

$N_{F,x}$ = Number of floors of sample building "x" (unitless)

It should be noted that the total area used ($A_{F,x}$) in the calculations is based on the floor area of sample buildings, not the exact residential area. This is due to the fact that the exact residential area data could not be obtained from the GIS database or any other public data source. If the exact residential data would be obtained, natural gas and electricity consumptions of only dwelling units would be taken into account. However, since the floor area was used, taking the common meters of buildings and/or building complexes into account in addition to the dwelling units' meters was decided to be a more appropriate approach. Therefore, natural gas and electricity consumptions recorded by common meters were also considered within total consumptions of sample buildings.

Minimum and maximum consumption values for the years 2014, 2015, 2016 and 2017 were calculated as individual scenarios by applying equations (3) and (4). Calculation of yearly and unit area-based consumptions based on the monthly electricity (kWh) and natural gas (Sm^3) consumption values is provided in APPENDIX C Accordingly, results of scenarios 1 to 8 are presented below:

Scenario 1: 2017 Maximum

$$E^*_{DH,2017max} = \frac{E_{DH,2017max}}{A_{F,DH}\ x\ N_{F,DH}} = \frac{395{,}819.9\ kWh}{1226\ m^2\ x\ 18} = \frac{395{,}819.9\ kWh}{22{,}068\ m^2}$$

$$= 17.94\ kWh/m^2$$

$$E^*_{CH,2017max} = \frac{E_{CH,2017max}}{A_{F,CH}\ x\ N_{F,CH}} = \frac{79{,}530.5\ kWh}{527\ m^2\ x\ 8} = \frac{79{,}530.5\ kWh}{4216\ m^2}$$

$$= 18.86\ kWh/m^2$$

$$E^*_{IH,2017max} = \frac{E_{IH,2017max}}{A_{F,IH}\ x\ N_{F,IH}} = \frac{65{,}369.6\ kWh}{529\ m^2\ x\ 6} = \frac{65{,}369.6\ kWh}{3174\ m^2}$$

$$= 20.60\ kWh/m^2$$

Consumptions and total areas of the four SH samples (SH-1, SH-2, SH-3 and SH-4) were merged and analyzed together as a single body to obtain a representative consumption value for SHs, which will be denoted as "SH" hereinafter. The said calculation can be seen in the equation below:

$$E^*_{SH,2017max} = \frac{E_{SH,2017max}}{A_{F,SH}\ x\ N_{F,SH}}$$

$$= \frac{20{,}561.7\ kWh}{(67m^2\ x\ 2) + (70m^2\ x\ 2) + (102m^2\ x\ 3) + (128m^2\ x\ 3)}$$

$$= \frac{20{,}561.7\ kWh}{964\ m^2} = 21.33\ kWh/m^2$$

For the calculation of unit area-based natural gas consumption of DH-type sample building, total area was considered as the total floor area of the whole building complex. In other words, all 7 blocks were taken into account as shown in the equation below, since the consumption values belonged to the common heating center of Saygınkent.

$$NG^*_{DH,2017max} = \frac{NG_{DH,2017max}}{A_{F,DH}\ x\ N_{F,DH}} = \frac{971{,}402.89\ Sm^3}{1226\ m^2\ x\ 18\ x\ 7} = \frac{971{,}402.89\ Sm^3}{154{,}476\ m^2}$$

$$= 6.29\ Sm^3/m^2$$

$$NG^*_{CH,2017max} = \frac{NG_{CH,2017max}}{A_{F,CH}\ x\ N_{F,CH}} = \frac{29{,}028.07\ Sm^3}{4216\ m^2} = 6.89\ Sm^3/m^2$$

$$NG^*_{IH,2017max} = \frac{NG_{IH,2017max}}{A_{F,IH}\ x\ N_{F,IH}} = \frac{25{,}267.92\ Sm^3}{3174\ m^2} = 7.96\ Sm^3/m^2$$

$$NG^*_{SH,2017max} = \frac{NG_{SH,2017max}}{A_{F,SH}\ x\ N_{F,SH}} = \frac{8812.43\ Sm^3}{964\ m^2} = 9.14\ Sm^3/m^2$$

Scenario 2: 2017 Minimum

$$E^*_{DH,2017min} = \frac{383{,}053.2\ kWh}{22{,}068\ m^2} = 17.36\ kWh/m^2$$

$$E^*_{CH,2017min} = \frac{77{,}263.9\ kWh}{4216\ m^2} = 18.33\ kWh/m^2$$

$$E^*_{IH,2017min} = \frac{65{,}369.6\ kWh}{3174\ m^2} = 20.60\ kWh/m^2$$

$$E^*_{SH,2017min} = \frac{20{,}561.7\ kWh}{964\ m^2} = 21.33\ kWh/m^2$$

$$NG^*_{DH,2017min} = \frac{971{,}402.89\ Sm^3}{154{,}476\ m^2} = 6.29\ Sm^3/m^2$$

$$NG^*_{CH,2017min} = \frac{28{,}885.98\ Sm^3}{4216\ m^2} = 6.85\ Sm^3/m^2$$

$$NG^{*}{}_{IH,2017min} = \frac{25{,}124.17\ Sm^3}{3174\ m^2} = 7.92\ Sm^3/m^2$$

$$NG^{*}{}_{SH,2017min} = \frac{8812.43\ Sm^3}{964\ m^2} = 9.14\ Sm^3/m^2$$

Scenarios 3 to 8 were calculated with the same approach followed in Scenarios 1 and 2; and are presented in Table 4-1.

Table 4-1. Unit-area based Consumptions for Scenarios 3 to 8

Scenario 3: 2016 Maximum	***Scenario 4: 2016 Minimum***
$E^{*}_{DH,2016max} = \frac{377,985.1\ kWh}{22,068\ m^2} = 17.13\ kWh/m^2$	$E^{*}_{DH,2016min} = \frac{368,139.9\ kWh}{22,068\ m^2} = 16.68\ kWh/m^2$
$E^{*}_{CH,2016max} = \frac{69,785.8\ kWh}{4216\ m^2} = 16.55\ kWh/m^2$	$E^{*}_{CH,2016min} = \frac{69,785.8\ kWh}{4216\ m^2} = 16.55\ kWh/m^2$
$E^{*}_{IH,2016max} = \frac{63,088.6\ kWh}{3174\ m^2} = 19.88\ kWh/m^2$	$E^{*}_{IH,2016min} = \frac{63,088.6\ kWh}{3174\ m^2} = 19.88\ kWh/m^2$
$E^{*}_{SH,2016max} = \frac{19,037.1\ kWh}{964\ m^2} = 19.75\ kWh/m^2$	$E^{*}_{SH,2016min} = \frac{18,274.1\ kWh}{964\ m^2} = 18.96\ kWh/m^2$
$NG^{*}_{DH,2016max} = \frac{853,978.78\ Sm^3}{154,476\ m^2} = 5.53\ Sm^3/m^2$	$NG^{*}_{DH,2016min} = \frac{853,978.78\ Sm^3}{154,476\ m^2} = 5.53\ Sm^3/m^2$
$NG^{*}_{CH,2016max} = \frac{25,512.05\ Sm^3}{4216\ m^2} = 6.05\ Sm^3/m^2$	$NG^{*}_{CH,2016min} = \frac{25,512.05\ Sm^3}{4216\ m^2} = 6.05\ Sm^3/m^2$
$NG^{*}_{IH,2016max} = \frac{22,173.86\ Sm^3}{3174\ m^2} = 6.99\ Sm^3/m^2$	$NG^{*}_{IH,2016min} = \frac{22,173.86\ Sm^3}{3174\ m^2} = 6.99\ Sm^3/m^2$
$NG^{*}_{SH,2016max} = \frac{7665.74\ Sm^3}{964\ m^2} = 7.95\ Sm^3/m^2$	$NG^{*}_{SH,2016min} = \frac{7665.74\ Sm^3}{964\ m^2} = 7.95\ Sm^3/m^2$

Table 4-1. Unit-area based Consumptions for Scenarios 3 to 8 (continued)

Scenario 5: 2015 Maximum	***Scenario 6: 2015 Minimum***
$E^*_{DH,2015max} = \dfrac{381{,}335.3\ kWh}{22{,}068\ m^2} = 17.28\ kWh/m^2$	$E^*_{DH,2015min} = \dfrac{368{,}654.1\ kWh}{22{,}068\ m^2} = 16.71\ kWh/m^2$
$E^*_{CH,2015max} = \dfrac{69{,}207.8\ kWh}{4216\ m^2} = 16.42\ kWh/m^2$	$E^*_{CH,2015min} = \dfrac{68{,}700.8\ kWh}{4216\ m^2} = 16.30\ kWh/m^2$
$E^*_{IH,2015max} = \dfrac{63{,}950.8\ kWh}{3174\ m^2} = 20.15\ kWh/m^2$	$E^*_{IH,2015min} = \dfrac{63{,}950.8\ kWh}{3174\ m^2} = 20.15\ kWh/m^2$
$E^*_{SH,2015max} = \dfrac{18{,}597.4\ kWh}{964\ m^2} = 19.29\ kWh/m^2$	$E^*_{SH,2015min} = \dfrac{9047.2\ kWh}{964\ m^2} = 9.39\ kWh/m^2$
$NG^*_{DH,2015max} = \dfrac{900{,}132.62\ Sm^3}{154{,}476\ m^2} = 5.83\ Sm^3/m^2$	$NG^*_{DH,2015min} = \dfrac{900{,}132.62\ Sm^3}{154{,}476\ m^2} = 5.83\ Sm^3/m^2$
$NG^*_{CH,2015max} = \dfrac{26{,}544.70\ Sm^3}{4216\ m^2} = 6.30\ Sm^3/m^2$	$NG^*_{CH,2015min} = \dfrac{26{,}386.38\ Sm^3}{4216\ m^2} = 6.26\ Sm^3/m^2$
$NG^*_{IH,2015max} = \dfrac{22{,}207.23\ Sm^3}{3174\ m^2} = 7.00\ Sm^3/m^2$	$NG^*_{IH,2015min} = \dfrac{21{,}923.24\ Sm^3}{3174\ m^2} = 6.91\ Sm^3/m^2$
$NG^*_{SH,2015max} = \dfrac{7909.30\ Sm^3}{964\ m^2} = 8.20\ Sm^3/m^2$	$NG^*_{SH,2015min} = \dfrac{5178.93\ Sm^3}{964\ m^2} = 5.37\ Sm^3/m^2$

Table 4-1. Unit-area based Consumptions for Scenarios 3 to 8 (continued)

Scenario 7: 2014 Maximum	***Scenario 8: 2014 Minimum***
$E^*_{DH,2014max} = \frac{367{,}458.1\ kWh}{22{,}068\ m^2} = 16.65\ kWh/m^2$	$E^*_{DH,2014min} = \frac{347{,}535.8\ kWh}{22{,}068\ m^2} = 15.75\ kWh/m^2$
$E^*_{CH,2014max} = \frac{69{,}307.4\ kWh}{4216\ m^2} = 16.44\ kWh/m^2$	$E^*_{CH,2014min} = \frac{64{,}402.2\ kWh}{4216\ m^2} = 15.28\ kWh/m^2$
$E^*_{IH,2014max} = \frac{62{,}215.6\ kWh}{3174\ m^2} = 19.60\ kWh/m^2$	$E^*_{IH,2014min} = \frac{60{,}785.5\ kWh}{3174\ m^2} = 19.15\ kWh/m^2$
$E^*_{SH,2014max} = \frac{18{,}481.6\ kWh}{964\ m^2} = 19.17\ kWh/m^2$	$E^*_{SH,2014min} = \frac{4503.3\ kWh}{964\ m^2} = 4.67 kWh/m^2$
$NG^*_{DH,2014max} = \frac{849{,}391.55\ Sm^3}{154{,}476\ m^2} = 5.50\ Sm^3/m^2$	$NG^*_{DH,2014min} = \frac{849{,}391.55\ Sm^3}{154{,}476\ m^2} = 5.50\ Sm^3/m^2$
$NG^*_{CH,2014max} = \frac{25{,}422.58\ Sm^3}{4216\ m^2} = 6.03\ Sm^3/m^2$	$NG^*_{CH,2014min} = \frac{24{,}962.48\ Sm^3}{4216\ m^2} = 5.92\ Sm^3/m^2$
$NG^*_{IH,2014max} = \frac{20{,}556.01\ Sm^3}{3174\ m^2} = 6.48\ Sm^3/m^2$	$NG^*_{IH,2014min} = \frac{19{,}867.84\ Sm^3}{3174\ m^2} = 6.26\ Sm^3/m^2$
$NG^*_{SH,2014max} = \frac{7286.82\ Sm^3}{964\ m^2} = 7.56\ Sm^3/m^2$	$NG^*_{SH,2014min} = \frac{2562.83\ Sm^3}{964\ m^2} = 2.66\ Sm^3/m^2$

3.2 Calculation of Residential CF in the Area of Study

After obtaining the representative values for building types in the area of study in Step 1, $CF_{res,NG,}$ $CF_{res,electricity;}$ and therefore, $CF_{res,total}$ of sample buildings was calculated for Scenarios 1 to 8.

The main approach followed in CF calculation was based on Equation (1), which requires "Activity Data" and "Emission Factor" as inputs. More specifically, $CF_{res,total}$ of each residential customer buildings due to natural gas and electricity consumption were calculated based on Equation (5) and Equation (6) below:

$$CF_{res,NG,i} = (NG^*_{x,y}\ x\ A_F\ x\ N_F\ x\ EF_{NG})\ /\ 1000 \tag{5}$$

where:

$CF_{res,NG,i}$ = Carbon footprint of customer building "i" due to residential natural gas consumption (tCO_2)

$NG^*_{x,y}$ = Representative natural gas consumption amount of sample building "x" per unit area in year "y" (Sm^3/m^2)

A_F = Floor area of customer building (m^2)

N_F = Number of floors of customer building (unitless)

EF_{NG} = Default CO_2 emission factor due to stationary natural gas combustion in the residential sector[2] = 56,100 $kgCO_2/TJ$ = 2.1488 $kgCO_2/Sm^3$

$$CF_{res,electricity,i} = (E^*_{x,y}\ x\ A_F\ x\ N_F\ x\ EF_{elec})\ /\ 1000 \tag{6}$$

where:

$CF_{res,electricity,i}$ = Carbon footprint of customer building "i" due to residential electricity consumption (tCO_2)

[2] IPCC Emission Factor Database (IPCC, 2018)

$E^*_{x,y}$ = Representative electricity consumption amount of sample building "x" per unit area in year "y" (kWh/m^2)

A_F = Floor area of customer building (m^2)

N_F = Number of floors of customer building (unitless)

EF_{elec} = CO_2 emission factor for Turkish grid[3] = 0.5459 $kgCO_2/kWh$

Carbon footprint of all 3807 residential customer buildings within the GIS database were calculated by applying Equations (5) and (6) for Scenarios 1 to 8. This process was carried out by importing the GIS database into Excel and assigning the associated unit area-based consumption value ($E^*_{x,y}$ or $NG^*_{x,y}$) calculated in Section 3.1 to each customer building based on their type (DH, CH, IH or SH). Eventually, the total residential CF in the area of study ($CF_{res,total}$) was calculated for each scenario based on Equation (7) below:

$$CF_{res,total} = \sum_{i=1}^{3807} CF_{res,NG,i} + CF_{res,electricity,i} \quad (7)$$

After calculating the $CF_{res,total}$ values, per capita $CF_{res,total}$ was also calculated for each scenario. For per capita CF calculation, total population in the area of study was achieved by assuming the household population as "3.3" in line with Turkish Statistical Institute (TSI)'s statistics for Bursa (Turkish Statistical Institute, 2017). By multiplying "3.3" with the number of dwelling unit of each customer building, customer building populations were found; and consequently, the total population in the area was calculated as "94,304". Accordingly, average per capita $CF_{res,total}$ was found by dividing the $CF_{res,total}$ value of each scenario to 94,304. Results of Equations (5), (6) and (7) are provided in the following Section together with the summary of the results obtained in Section 3.1. A sample CF calculation worksheet is provided in APPENDIX D.

[3] (Dalkic, Balaban, Tuydes-Yaman, & Celikkol-Kocak, 2017)

Following the same approach, per capita $CF_{res,total}$ of each customer building was also calculated for each scenario to be used in spatial analyses. This calculation was done by dividing the $CF_{res,total}$ value of each customer building to the population of each customer building. In addition, per capita $CF_{res,NG}$ of each customer building was calculated only for *Scenario 1: 2017 Maximum* to better interpret the differences between natural gas-driven CFs of CH/DH and IH-type residential heating systems. Discussion of the results of these calculations are presented in Section 3.5 and Section 3.6.

3.3 Comparison and Discussion of CF Calculation Results

The sample building consumptions per unit area and results of CF calculations are provided in Table 4-2 below for Scenarios 1 to 8. A sample CF calculation worksheet is provided in APPENDIX D.

Table 4-2. Summary of the Results for Scenarios 1 to 8

Scenario 1: 2017 Maximum				
Parameter/ Building Type	**DH**	**CH**	**IH**	**SH**
$E^*_{x,y}$ (kWh/m^2)	17.94	18.86	20.60	21.33
$NG^*_{x,y}$ (Sm^3/m^2)	6.29	6.89	7.96	9.14
$CF_{res,electricity}$ (tCO_2)	47,458.23			
$CF_{res,NG}$ (tCO_2)	72,064.06			
$CF_{res,total}$ (tCO_2)	119,522.30			
Per Capita $CF_{res,total}$ (tCO_2/person)	1.27			

Scenario 2: 2017 Minimum				
Parameter/ Building Type	**DH**	**CH**	**IH**	**SH**
$E^*_{x,y}$ (kWh/m^2)	17.36	18.33	20.60	21.33
$NG^*_{x,y}$ (Sm^3/m^2)	6.29	6.85	7.92	9.14
$CF_{res,electricity}$ (tCO_2)	47,171.58			
$CF_{res,NG}$ (tCO_2)	71,750.10			
$CF_{res,total}$ (tCO_2)	118,921.67			
Per Capita $CF_{res,total}$ (tCO_2/person)	1.26			

Scenario 3: 2016 Maximum				
Parameter/ Building Type	**DH**	**CH**	**IH**	**SH**
$E^*_{x,y}$ (kWh/m^2)	17.13	16.55	19.88	19.75
$NG^*_{x,y}$ (Sm^3/m^2)	5.53	6.05	6.99	7.95
$CF_{res,electricity}$ (tCO_2)	44,904.74			
$CF_{res,NG}$ (tCO_2)	63,214.91			
$CF_{res,total}$ (tCO_2)	108,119.65			
Per Capita $CF_{res,total}$ (tCO_2/person)	1.15			

Scenario 4: 2016 Minimum				
Parameter/ Building Type	**DH**	**CH**	**IH**	**SH**
$E^*_{x,y}$ (kWh/m^2)	16.68	16.55	19.88	18.96
$NG^*_{x,y}$ (Sm^3/m^2)	5.53	6.05	6.99	7.95
$CF_{res,electricity}$ (tCO_2)	44,667.36			
$CF_{res,NG}$ (tCO_2)	63,214.91			
$CF_{res,total}$ (tCO_2)	107,882.27			
Per Capita $CF_{res,total}$ (tCO_2/person)	1.14			

Table 4-2. Summary of the Results for Scenarios 1 to 8 (continued)

Scenario 5: 2015 Maximum				
Parameter/ Building Type	**DH**	**CH**	**IH**	**SH**
$E^*_{x,y}$ (kWh/m^2)	17.28	16.42	20.15	19.29
$NG^*_{x,y}$ (Sm^3/m^2)	5.83	6.30	7.00	8.20
$CF_{res,electricity}$ (tCO_2)	45,189.32			
$CF_{res,NG}$ (tCO_2)	64,051.02			
$CF_{res,total}$ (tCO_2)	109,240.34			
Per Capita $CF_{res,total}$ (tCO_2/person)	1.16			

Scenario 6: 2015 Minimum				
Parameter/ Building Type	**DH**	**CH**	**IH**	**SH**
$E^*_{x,y}$ (kWh/m^2)	16.71	16.30	20.15	9.39
$NG^*_{x,y}$ (Sm^3/m^2)	5.83	6.26	6.91	5.37
$CF_{res,electricity}$ (tCO_2)	42,766.21			
$CF_{res,NG}$ (tCO_2)	60,830.55			
$CF_{res,total}$ (tCO_2)	103,596.76			
Per Capita $CF_{res,total}$ (tCO_2/person)	1.10			

Scenario 7: 2014 Maximum				
Parameter/ Building Type	**DH**	**CH**	**IH**	**SH**
$E^*_{x,y}$ (kWh/m^2)	16.65	16.44	19.60	19.17
$NG^*_{x,y}$ (Sm^3/m^2)	5.50	6.03	6.48	7.56
$CF_{res,electricity}$ (tCO_2)	44,224.27			
$CF_{res,NG}$ (tCO_2)	59,633.17			
$CF_{res,total}$ (tCO_2)	103,857.45			
Per Capita $CF_{res,total}$ (tCO_2/person)	1.10			

Scenario 8: 2014 Minimum				
Parameter/ Building Type	**DH**	**CH**	**IH**	**SH**
$E^*_{x,y}$ (kWh/m^2)	15.75	15.28	19.15	4.67
$NG^*_{x,y}$ (Sm^3/m^2)	5.50	5.92	6.26	2.66
$CF_{res,electricity}$ (tCO_2)	39,550.58			
$CF_{res,NG}$ (tCO_2)	53,591.33			
$CF_{res,total}$ (tCO_2)	93,141.91			
Per Capita $CF_{res,total}$ (tCO_2/person)	0.99			

It would be useful to first assess the general situation of Bursa based on the figures provided in Table 2-6 before commenting on the results obtained in Table 4-2 above. Three action plans prepared for Bursa are presented in Table 2-6, one being the “Bursa MM Corporate and Urban CF Inventory and SEAP” established in 2015; another one being the “Bursa Nilufer District Municipality SEAP” dated 2016, and the last one being “Bursa SECAP” dated 2017.

When Bursa is compared to Izmir (the third largest city of Turkey by population right before Bursa), it can be seen that Bursa had a slightly lower $CF_{res,total}$ **(2612.60 $ktCO_2$)** than that of Izmir **(2725.51 $ktCO_2$)** based on their 2014 inventories. This almost 100 $ktCO_2$ of difference may be a result of warmer summers in Izmir and correspondingly higher electricity consumption.

Likewise, when the 2014 inventory of Bursa is compared to 2012 inventory of Antalya (the fifth largest city of Turkey by population right after Bursa), it is seen that Bursa had a slightly higher $CF_{res,total}$ **(2612.60 $ktCO_2$)** than Antalya **(1235.41 $ktCO_2$)**. Apart from the two years difference between inventories, this almost 1400 $ktCO_2$ of difference is probably the result of much warmer winters in Antalya and correspondingly lower residential heating needs (i.e. Scope 1 emissions).

As per the per capita $CF_{res,total}$ results, it can be seen that Nilüfer District had a higher value **(0.99 tCO_2/person)** in the 2013 inventory than Bursa’s average **(0.94 tCO_2/person)** in the 2014 inventory. Since per capita CF is an indicator of life style and living standard, this difference may be due to the higher life standard and correspondingly higher energy consumptions within Nilufer District. It can also be seen that per capita $CF_{res,total}$ result of Nilufer District is almost equa.l to those of Maltepe and Cankaya Municipalities, which may be an indicator of similar life style and living standards within these districts.

After comparisons are made with other Turkish cities, Per Capita $CF_{res,total}$ results of some -mostly developed- cities were gathered in Table 4-3 below to see where Bursa stands among other cities in the world.

Table 4-3. Per Capita CFres,total Results from the World

City	Country HDI[4] Rank	Inventory Year	Followed Methodology	Per Capita $CF_{res,total}$ (tCO_2e/person)	Population	Reference
Melbourne	2	2009-2010	Guidelines Australian National Greenhouse&Energy Reporting Methodology	6.48*	101.0 K	(CDP, 2013)
Buenos Aires	45	2010	Proprietary methodology	1.29*	2.89 M	(CDP, 2013)
Durban	119	2013	GPC + IPCC	1.10*	3.52 M	(CDP, 2015)
Los Angeles	10	2013	GPC	1.55*	3.89 M	(City of Los Angeles, 2017)
Oslo	1	2013	GPC + IPCC	0.4*	647.7 K	(CDP, 2015)
Auckland	13	2015	GPC	0.43*	1.6 M	(Xie, 2017)
London	16	2015	Not stated	1.39*	8.67 M	(Greater London Authority, 2017)
Tokyo	17	2015	Not stated	1.79*	9.27 M	(Bureau of Environment, 2018)
San Francisco	10	2016	GPC	1.03*	870.8 K	(San Francisco Department of Environment, 2018)

* Not directly stated; but calculated by using the population figures or by the percentage distribution of emission sources given in the same document.

Since there is not a single, standard methodology being followed during the preparation of GHG inventories, assessing Bursa as "better" or "worse" than other cities would not be quite appropriate. Rather, more general comments can be made. Turkey ranks 71st in the HDI list, and the results of Bursa found in this study are quite close to those of Buenos Aires and Durban, which are not among the most developed cities. Still, according to the figures in the table, it can be stated that Bursa does not have a very bad standing and the results found in this study (1.15 tCO_2/person on the average) are slightly lower than the latest values of Los Angeles, London and Tokyo; which are among the most developed cities in the world. Although Australia ranks the 2nd in the HDI list, it can be seen that the 2010 results of Melbourne is almost 5 to 6-fold of other figures. On the other hand,

[4] HDI (Human Development Index) Rankings of 2015 (UNDP, 2016)

values as low as 0.4 tCO_2/person can also be seen in Oslo, Norway which ranks the 1st with its HDI, and Auckland, New Zealand that ranks 13th. Similar, and even lower figures should be taken as an example for Bursa and targets should be set accordingly.

Now that a picture of the general state of Bursa is formed in mind, the results provided in Table 4-2 can be discussed. According to the results, the difference between “minimum” and “maximum” scenarios is noticeable in 2014 and 2015; however, the difference becomes negligible for years 2016 and 2017. This is mainly due to lack of consumption data of two sample single houses in this study. As previously mentioned in Section 2.5, one of the sample buildings did not have any consumption data for 2014 and 2015 and another one did not have data for 2014. Hence, the original data was considered as the “minimum” scenario, in which it was assumed that the dwellers did not move in yet; while the “maximum” scenario was considered with 100% occupancy rate. It may be attributed to the possibility that 19 Mayıs Neighborhood is a relatively new neighborhood and the single houses here may be built/sold after 2015 (which was also observed from Google Street View when images before and after 2015 were compared). However, to better interpret the differences between “minimum” and “maximum” scenarios, and to minimize the margin of error, a much larger number of sample buildings have to be used. Given the limitation of this study, the results will be discussed in the general framework of all eight scenarios except the cases where the difference between minimum and maximum scenarios are distinct.

The interpretation and discussion of the calculation results can be listed as follows:

- The highest unit area-based natural gas consumptions belong to SH-type buildings, in which IH-type heating systems are used, in most of the scenarios. The general average of unit area-based natural gas consumption (i.e. the four-year average of all scenarios included) of SH-type buildings were calculated as **7.25 Sm^3/m^2**.
- The second highest unit area-based natural gas consumptions belong to IH-type buildings (the general average was calculated as **7.06 Sm^3/m^2**). As

expected, CH- and DH- type buildings had lower unit area-based natural gas consumptions (the general averages were calculated as **6.29 Sm^3/m^2** and **5.79 Sm^3/m^2**, respectively). The lowest figures were those of DH-type buildings since they are more efficient heating systems, which was consistent with the results of the previous study (Evren, 2015).

- As for the unit area-based electricity consumptions, IH-type buildings had the highest figure with the general average of **20.00 kWh/m^2**. The general averages of DH, CH and SH-type buildings were quite close to each other with **16.94, 16.84** and **16.74 kWh/m^2**, respectively.
- The per capita $CF_{res,total}$ ranged from **0.99** to **1.27 tCO_2/person** between 2014-2017, with an increasing trend through years. The general average of per capita $CF_{res,total}$ is calculated as **1.15 tCO_2/person,** which can be considered as a reasonable result when compared to the per capita $CF_{res,total}$ results of “Bursa MM Corporate and Urban CF Inventory and SEAP (2015)”, “Bursa Nilufer District Municipality SEAP (2016)” and "Bursa SECAP (2017)” found as **0.94**, **0.99 and 1.04 tCO_2/person**, respectively (see Table 2-6). Since actual consumption data and actual floor areas of buildings were used in this study instead of population-weighted calculations, finding a higher value is an expected and normal outcome.
- The $CF_{res,total}$ ranged from **93.14** to **119.52 $ktCO_2$** between 2014-2017, with an increasing trend through years. The general average of $CF_{res,total}$ is calculated as **108.04 $ktCO_2$,** which is not unreasonable when compared to the $CF_{res,total}$ results of the whole Nilufer District calculated in “Bursa Nilufer District Municipality SEAP (2016)” found as **356.71 $ktCO_2$** (see Table 2-6).
- The unit area-based consumptions and the CF values (including per capita $CF_{res,total}$) show a decreasing trend from Scenario 1 to Scenario 8 (i.e. from 2017 to 2014). The only exception was observed in Scenarios 3 and 5, where the 2015 maximum values were slightly larger than 2016 maximum values. This kind of exceptions may occur due to minor fluctuations in consumption patterns resulting from yearly temperature differences. More specifically, this minor difference may simply be due to a colder winter in

2015 in Bursa than in 2016 and/or a warmer summer in 2015 than in 2016; and correspondingly, a higher natural gas consumption in winter for indoor heating purposes and a higher electricity consumption in summer for air conditioning purposes. Except for such specific cases, consumption and CF values tend to increase by time, in parallel to the increasing global energy demand. In general, it was observed that electricity and natural gas consumptions increased from 2014 to 2017, which resulted in increasing $CF_{res,total}$ and per capita $CF_{res,total}$ values through years.

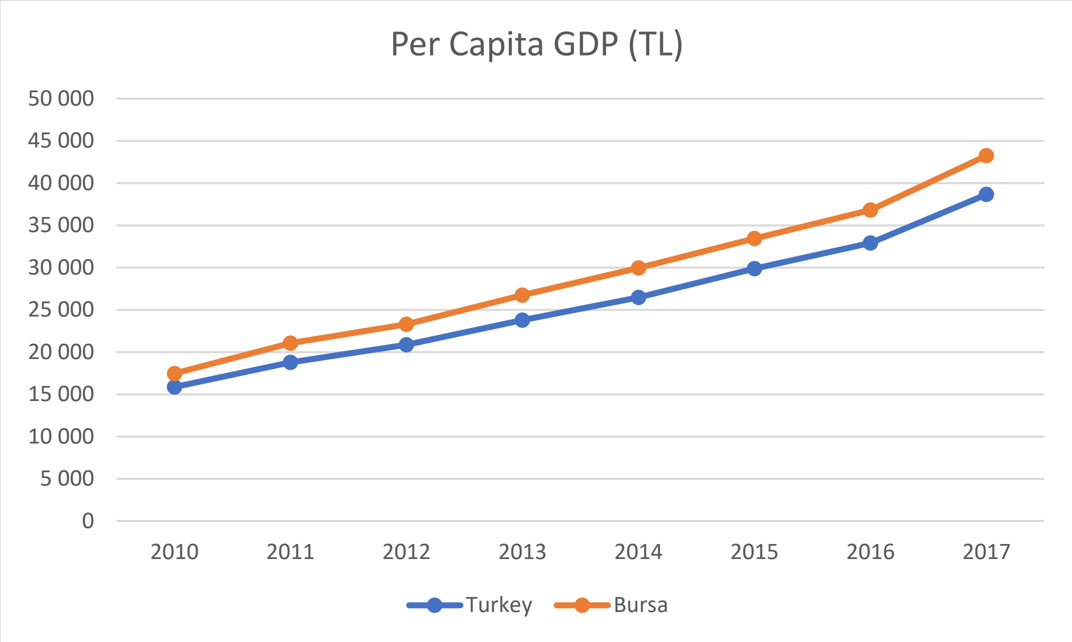
The increasing trend observed in consumptions and corresponding CF results might have various natural and/or anthropogenic as discussed below:

i. *Purely anthropogenic reasons:*

The increase may be solely based on the changes in life style and consumption habits, which is a natural and common reaction of human behavior to the modern world and consumption economy.

ii. *Level of income:*

The increasing trend might be a result of the increasing per capita Gross Domestic Product (GDP) in Turkey and also in Bursa. To investigate this possibility, per capita GDP values of Bursa and Turkey for 2010-2017 was obtained from TSI; and the results were summarized in Figure 4-1.



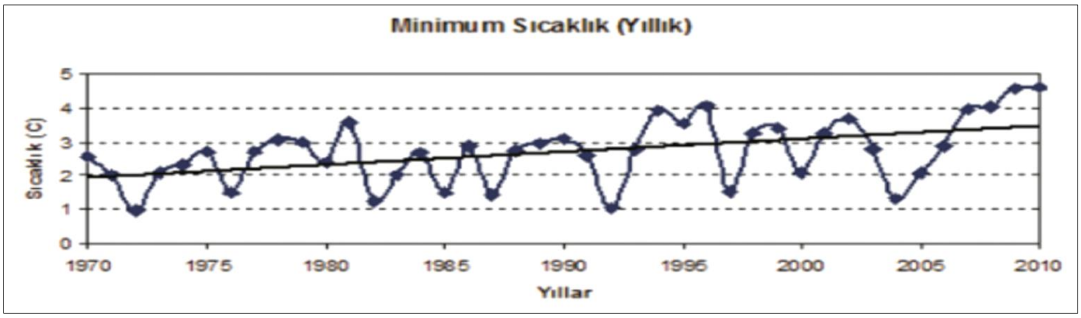
Source: (Turkish Statistical Institute, 2016) , (Turkish Statistical Institute, 2017)

Figure 4-1. Per Capita GDP Values in Turkey and Bursa (2010-2017)

As can be seen from the graph, the Per Capita GDP values in both Turkey and Bursa show an increasing trend from 2010 to 2017; and has increased from the levels of 15,000 TL to above 40,000 TL. Furthermore, Per Capita GDP values in Bursa is observed to be around 10% above Turkey. Therefore, the increase in Per Capita GDP in Bursa might be offered as a reason for the increasing consumption and CF results. It should be noted that province-based values were only available until 2014. Hence, the GDP values of Bursa for 2014-2017 was derived by using the average ratio of Bursa to Turkey, which was calculated as 1.12 based on the values provided for 2010-2014 period.

iii. Natural (climatic) reasons:

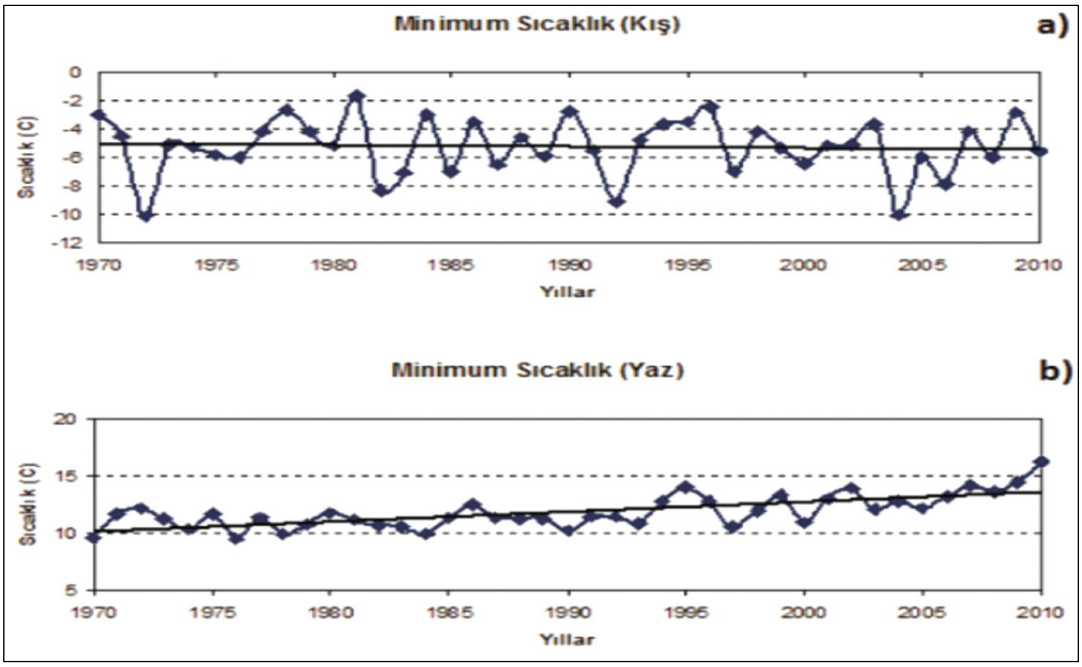
Seasonal temperature changes through years was also considered as one of the potential reasons for the increasing trend in consumption and CF. To investigate this possibility, fluctuations of yearly temperature values in Bursa were examined. According to data obtained from Bursa SECAP, yearly minimum temperature show an increasing trend in the 1970-2010 period, which can be seen in Figure 4-2.



Source: (Bursa Metropolitan Municipality, 2017)

Figure 4-2. Yearly Minimum Temperatures in Bursa (1970-2010)

Furthermore, seasonal variances in yearly temperatures were examined and it was seen that the minimum winter temperature has been decreasing by ~0.5 °C (see Figure 4-3, a) while minimum summer temperature has been increasing by ~2 °C (see Figure 4-3, b) in Bursa for the same period due to urban heat island effect (Bursa Metropolitan Municipality, 2017).



Source: (Bursa Metropolitan Municipality, 2017)

Figure 4-3. Seasonal Variances in Yearly Temperatures in Bursa (1970-2010)

In addition to the above data; minimum, maximum and average monthly temperatures recorded for 2014-2017 were obtained from the online Meteorological Data-Information Presentation and Sales System (Mevbis) of Turkish State

Meteorological Service to observe the fluctuations (Turkish State Meteorological Service, 2018). Accordingly, the winter and summer temperature data recorded by Nilüfer Meteorology Station are shown in Figure-x and Figure-Y, respectively.

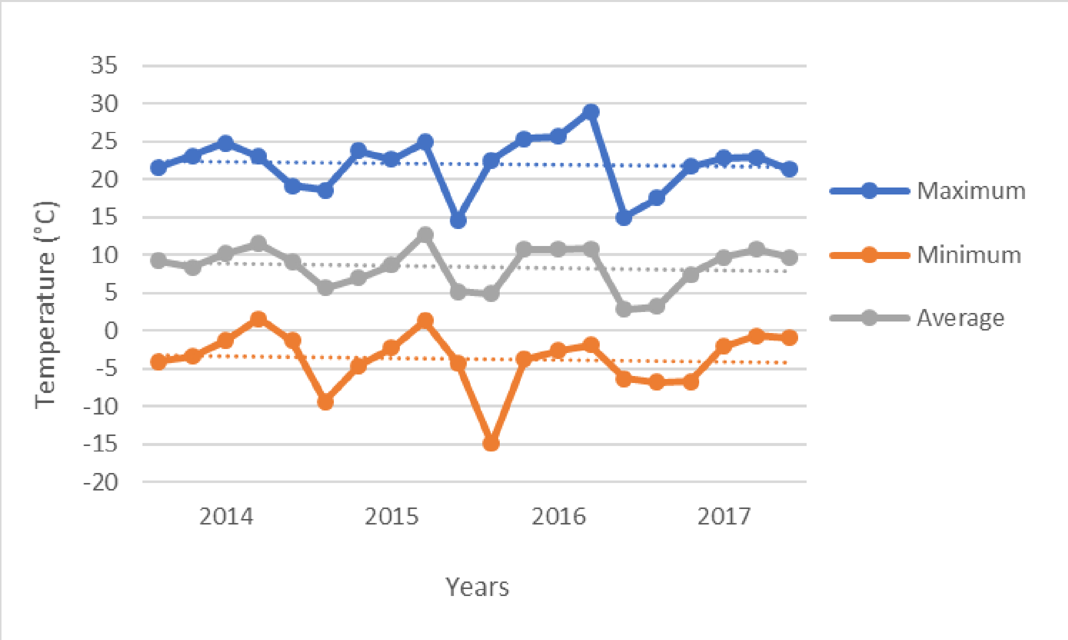


Figure 4-4. Minimum, Maximum and Average Winter Temperatures Recorded by Nilüfer Meteorology Station (2014-2017)

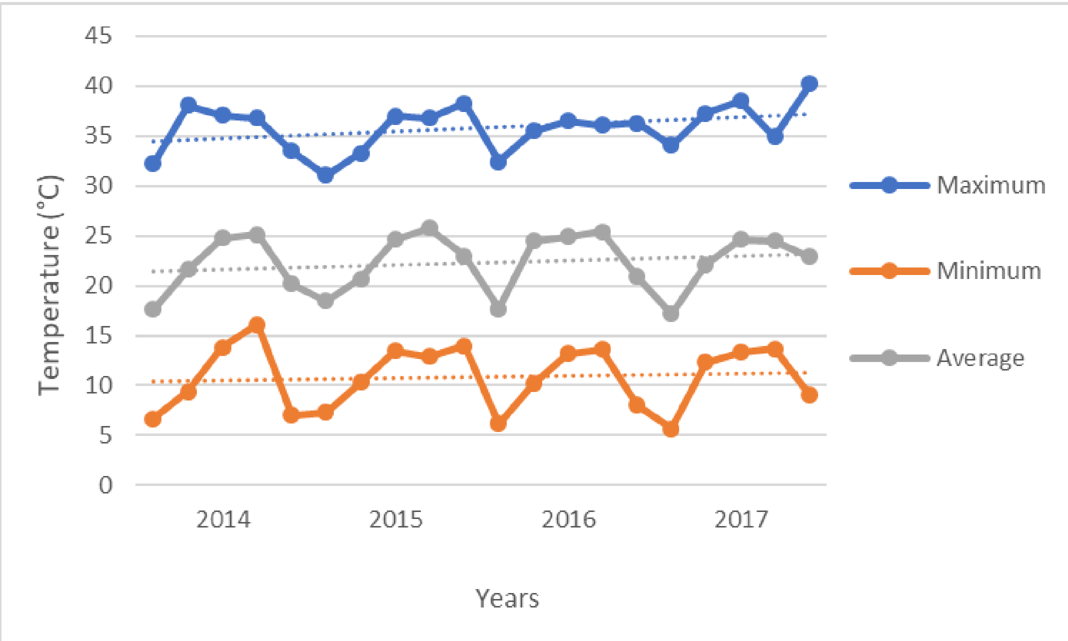


Figure 4-5. Minimum, Maximum and Average Summer Temperatures Recorded by Nilüfer Meteorology Station (2014-2017)

As the above graphs indicate; minimum, maximum and average winter temperatures all show a decreasing trend while summer temperatures show an increasing trend for the 2014-2017 period, in parallel to the previous years' data shown in Figure 4-3. Therefore, these findings on yearly and seasonal temperature variances might be considered as another reason for the increasing consumption and CF results. More specifically, lower winter temperatures and higher summer temperatures might have resulted in increased energy consumption by increasing the indoor heating load in winter and air conditioning load in summer.

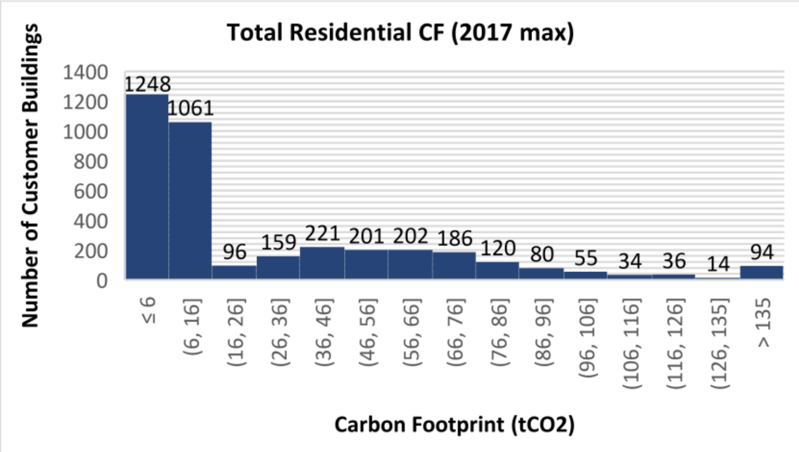
3.4 Results and Outputs of Spatial Analyses

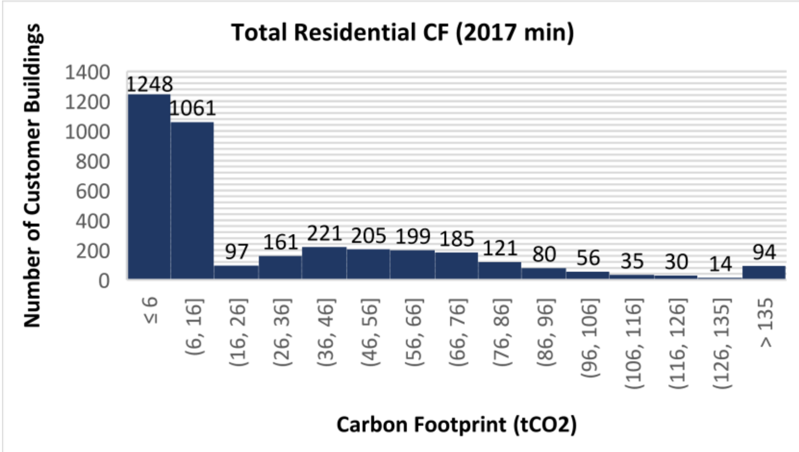
In this section, results of the statistical and spatial analyses performed for each scenario as mentioned in Section 2.7 are provided and their policy implications are discussed. The results of the analyses performed for $CF_{res,total}$ and Per Capita $CF_{res,total}$ are provided in the following order:

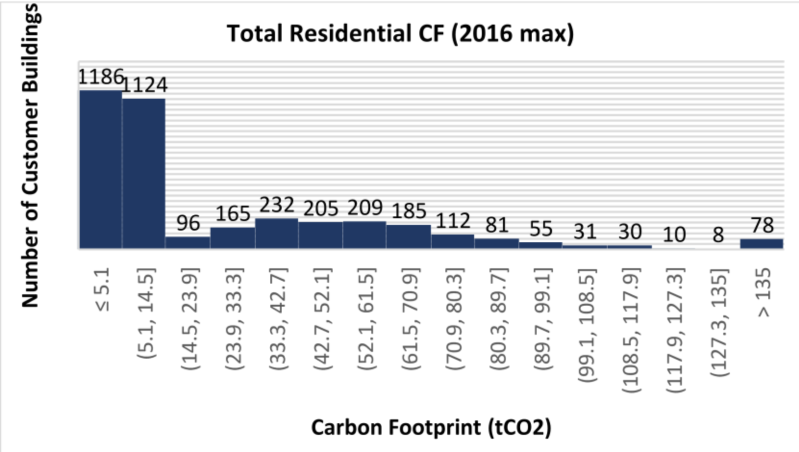
1. Histogram Graphs (Table 4-4 and Table 4-5)
2. Classification Maps for Customer Point Emissions (Figure 4-6 to Figure 4-21)
3. Hot Spot Analyses (Figure 4-22 to Figure 4-29) , and
4. Kernel Density Maps (Figure 4-30 to Figure 4-53).

Comments, discussions and policy implications driven from the results are presented in Section 3.5.

Table 4-4. Histogram Graphs for CFres,total







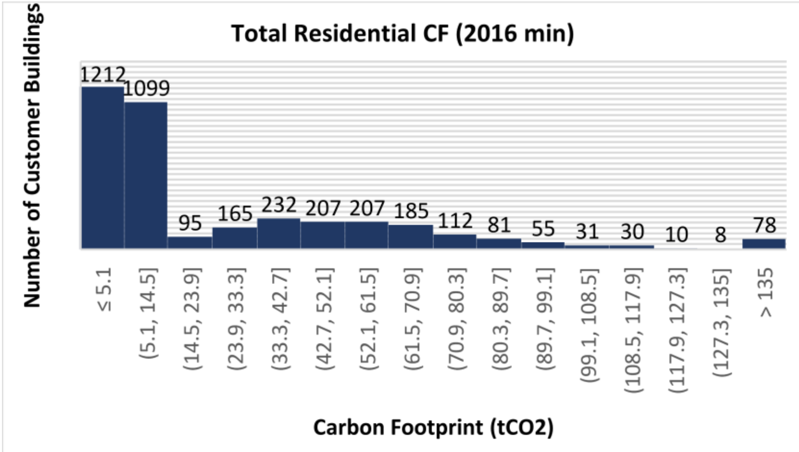
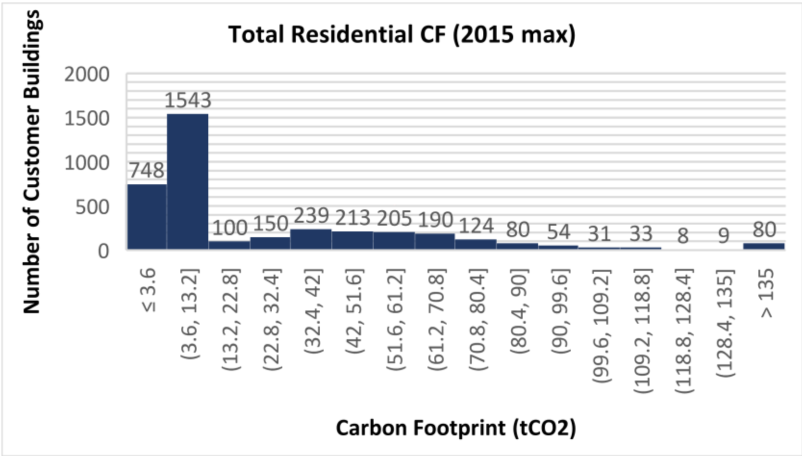
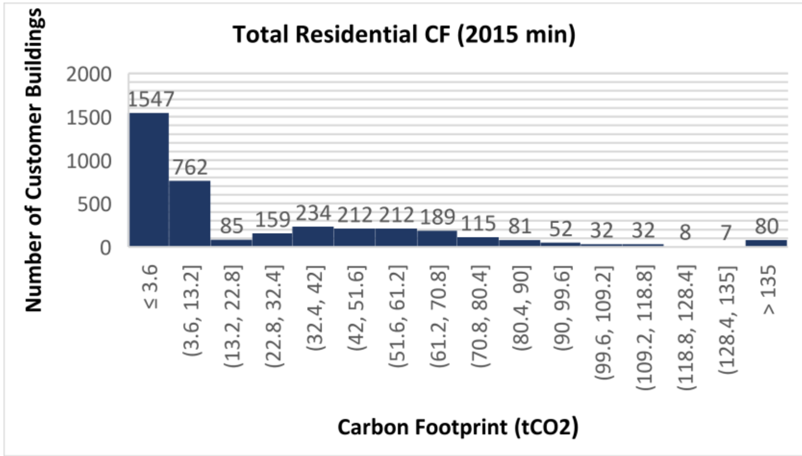
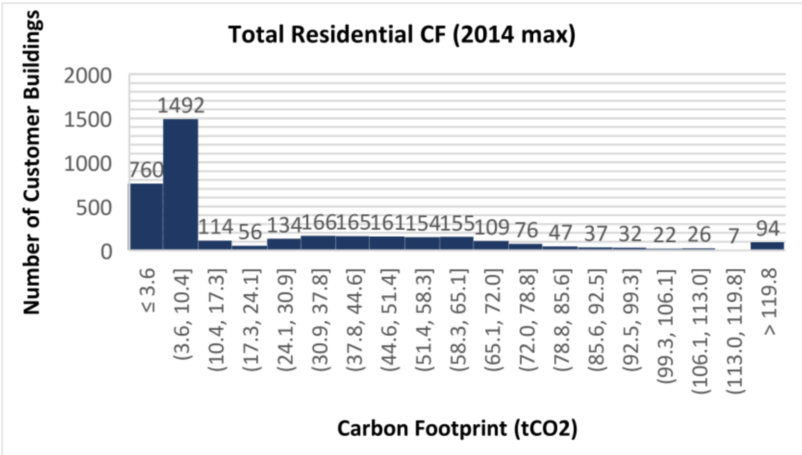


Table 4-4. Histogram Graphs for CFres,total (continued)







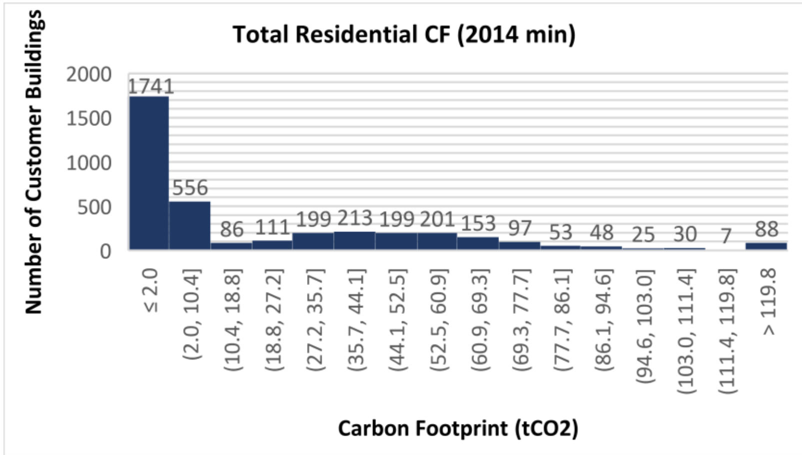
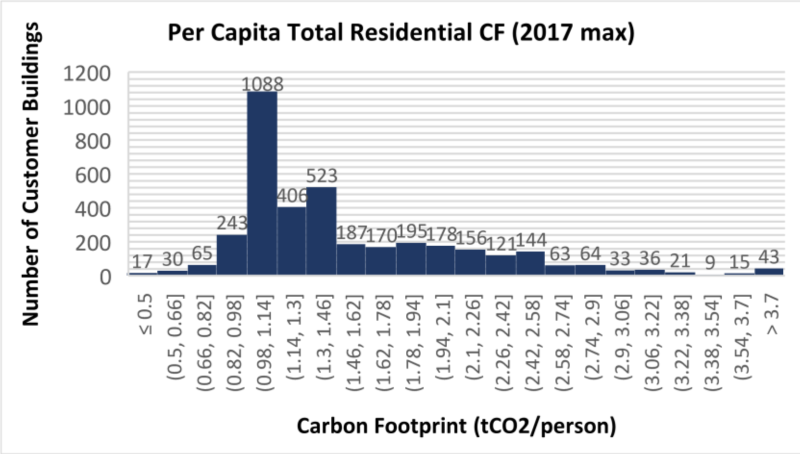
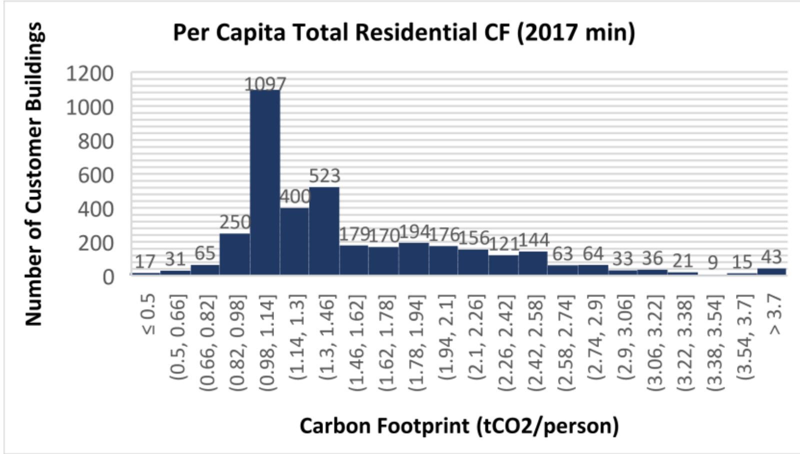
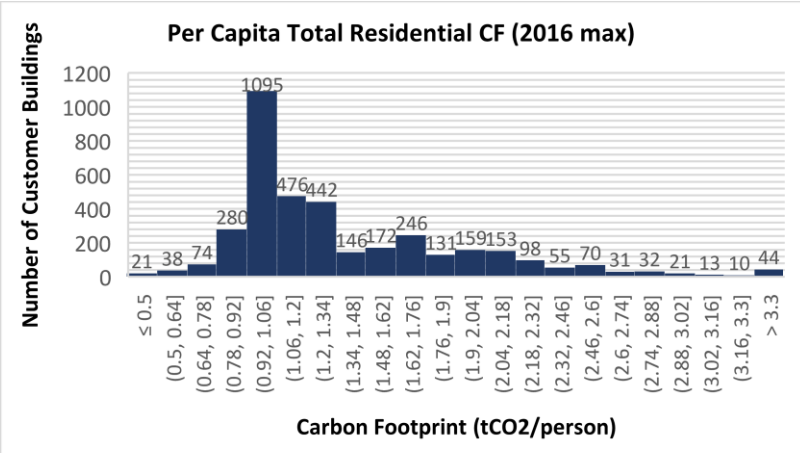


Table 4-5. Histogram Graphs for Per Capita CFres,total







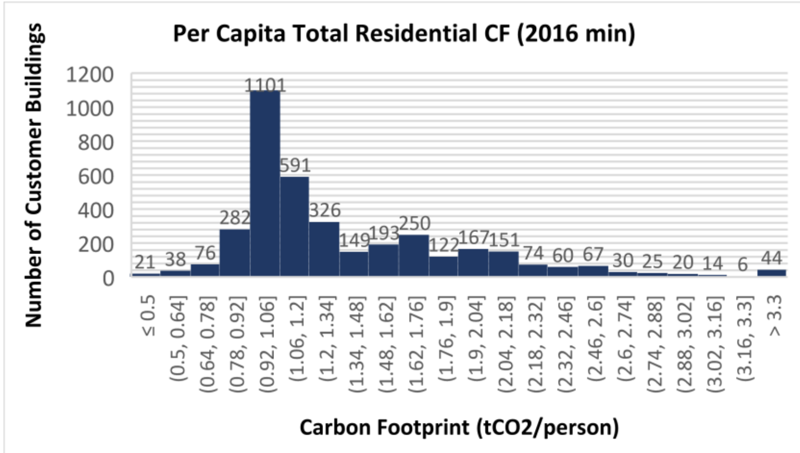
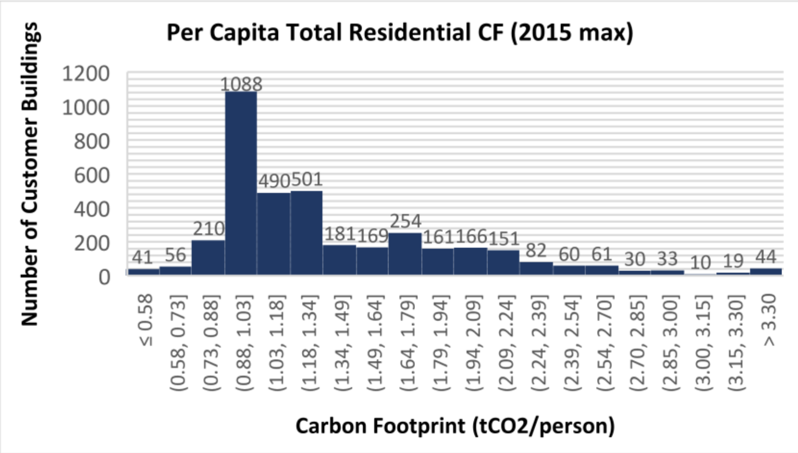
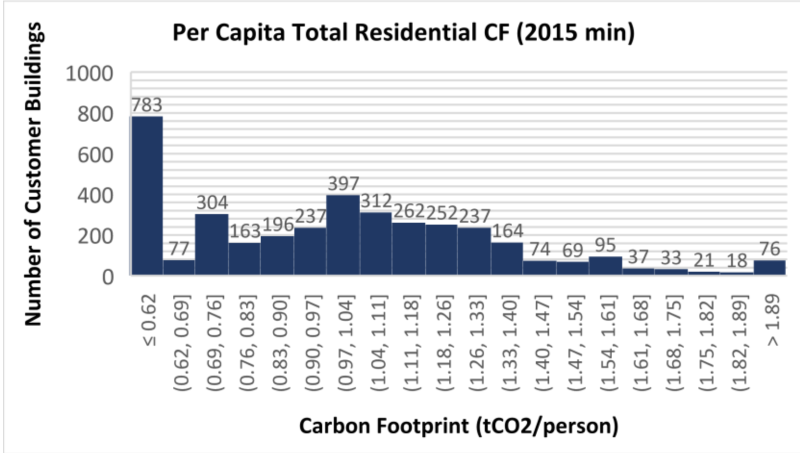
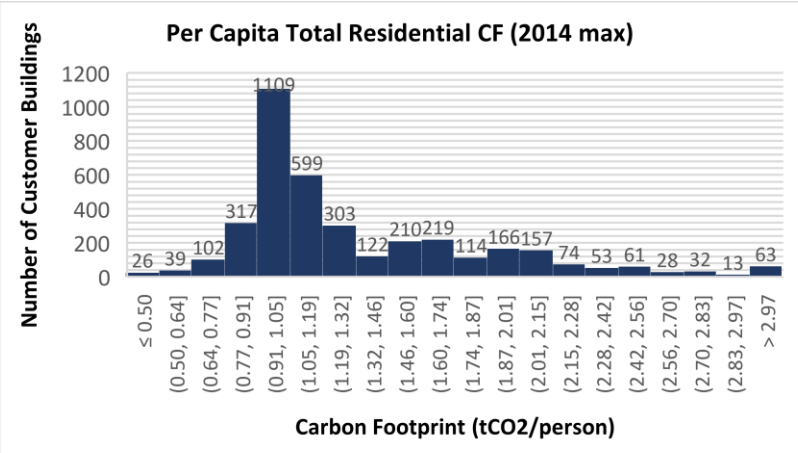
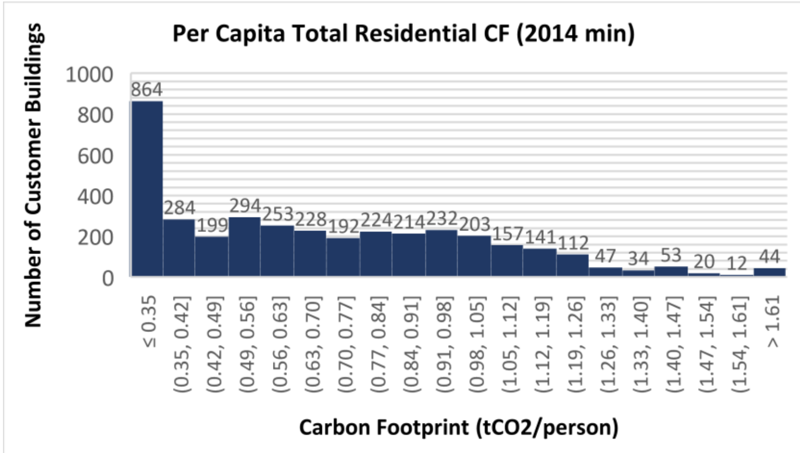


Table 4-5. Histogram Graphs for Per Capita CFres,total (continued)









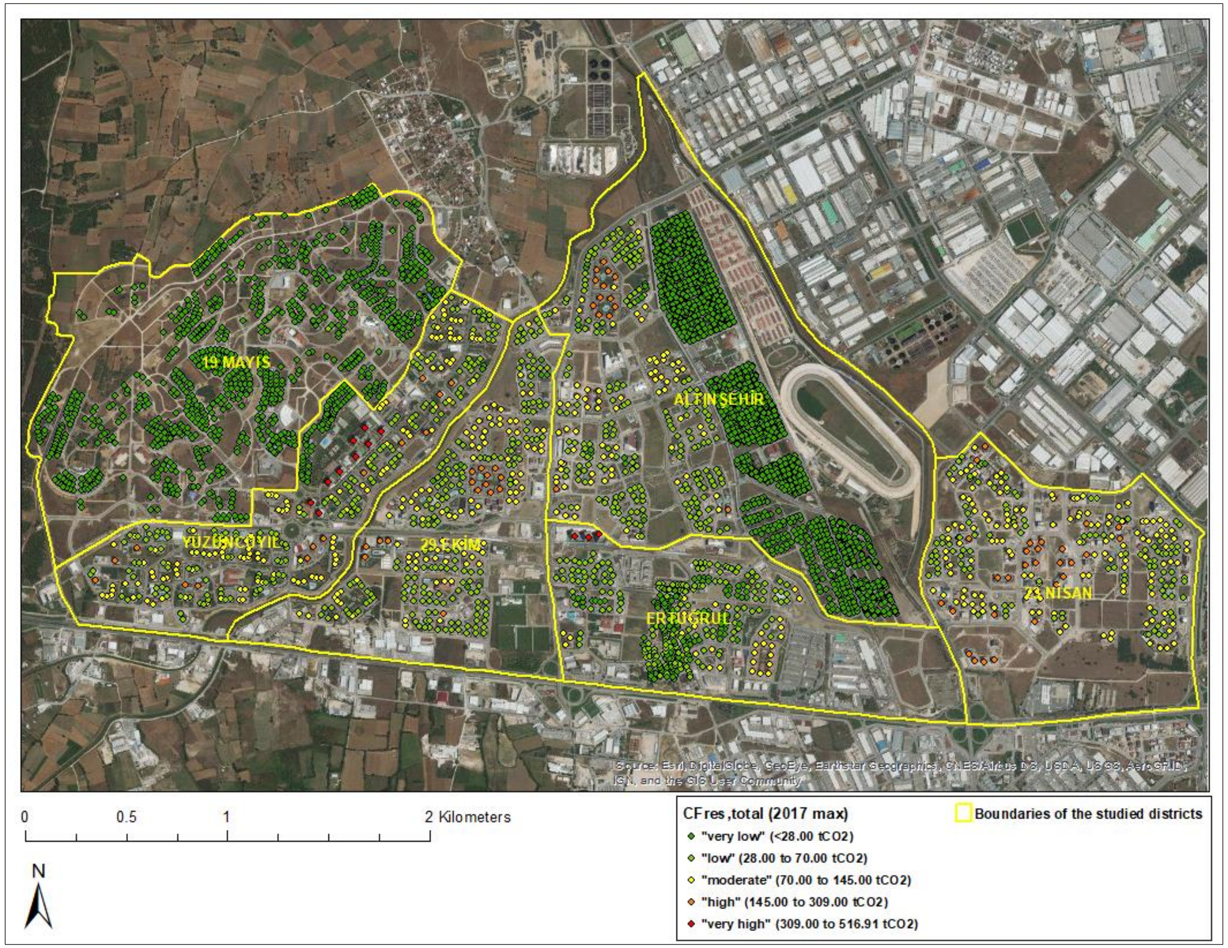


Figure 4-6. Classification of Customer Point Emissions for CFres,total (2017 max)

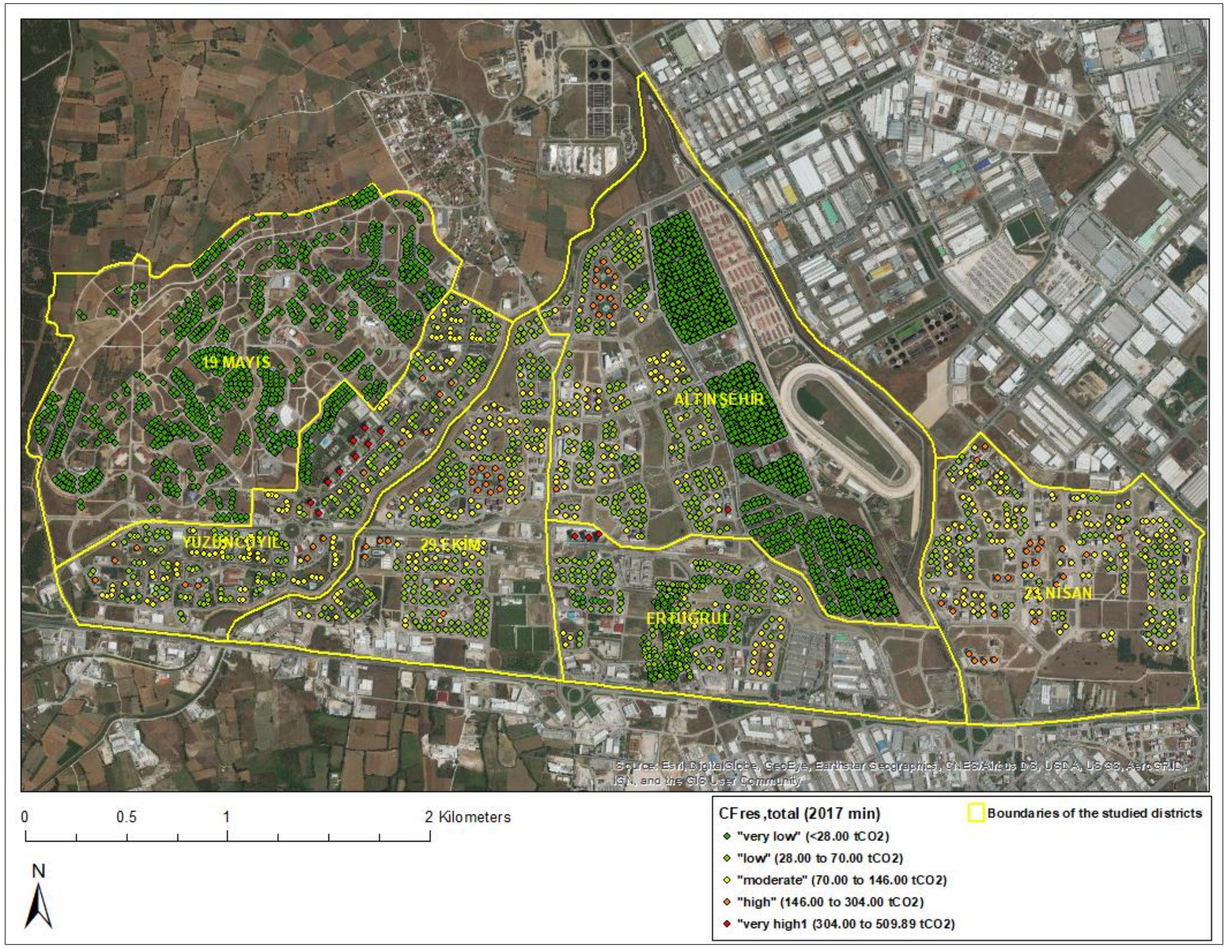


Figure 4-7. Classification of Customer Point Emissions for CFres,total (2017 min)

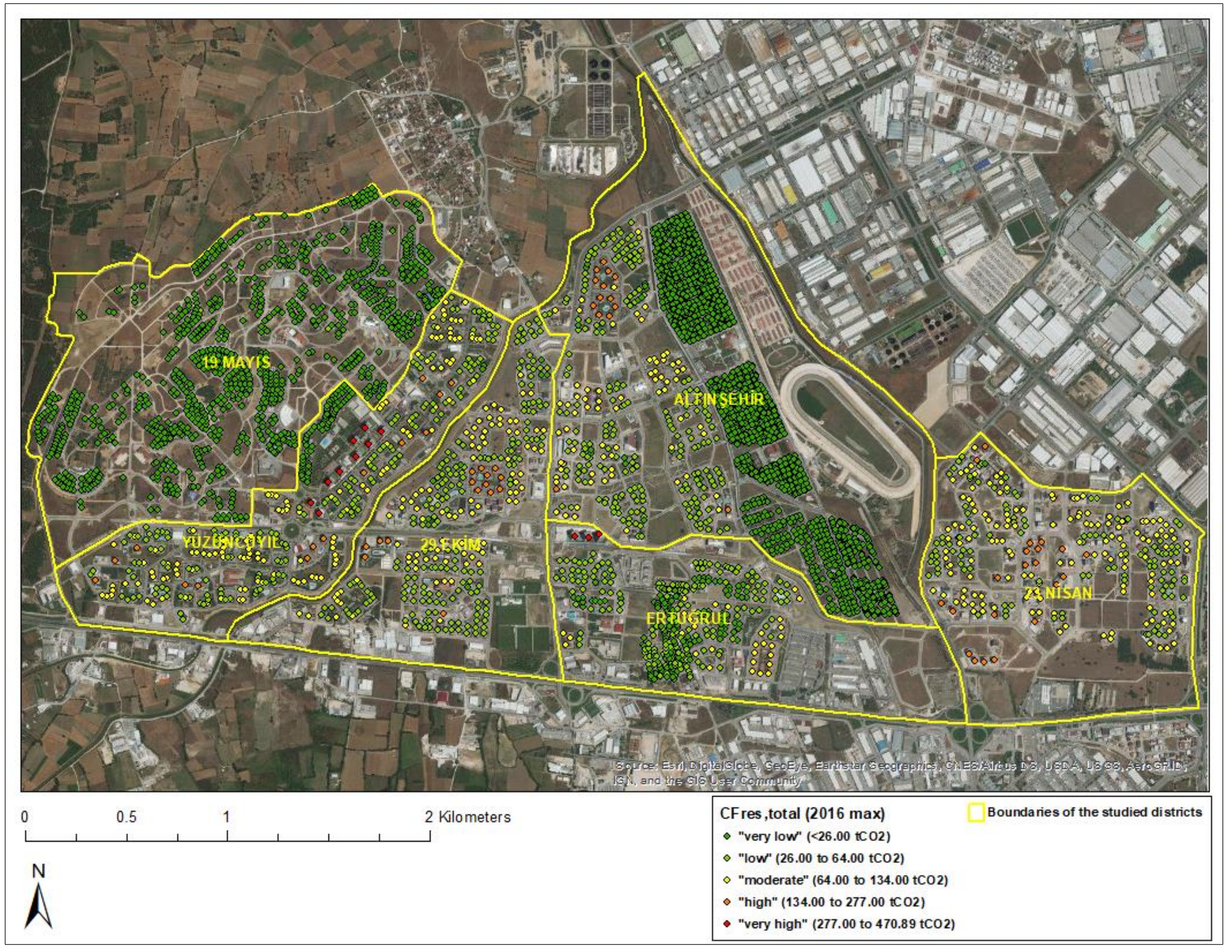


Figure 4-8. Classification of Customer Point Emissions for CFres,total (2016 max)

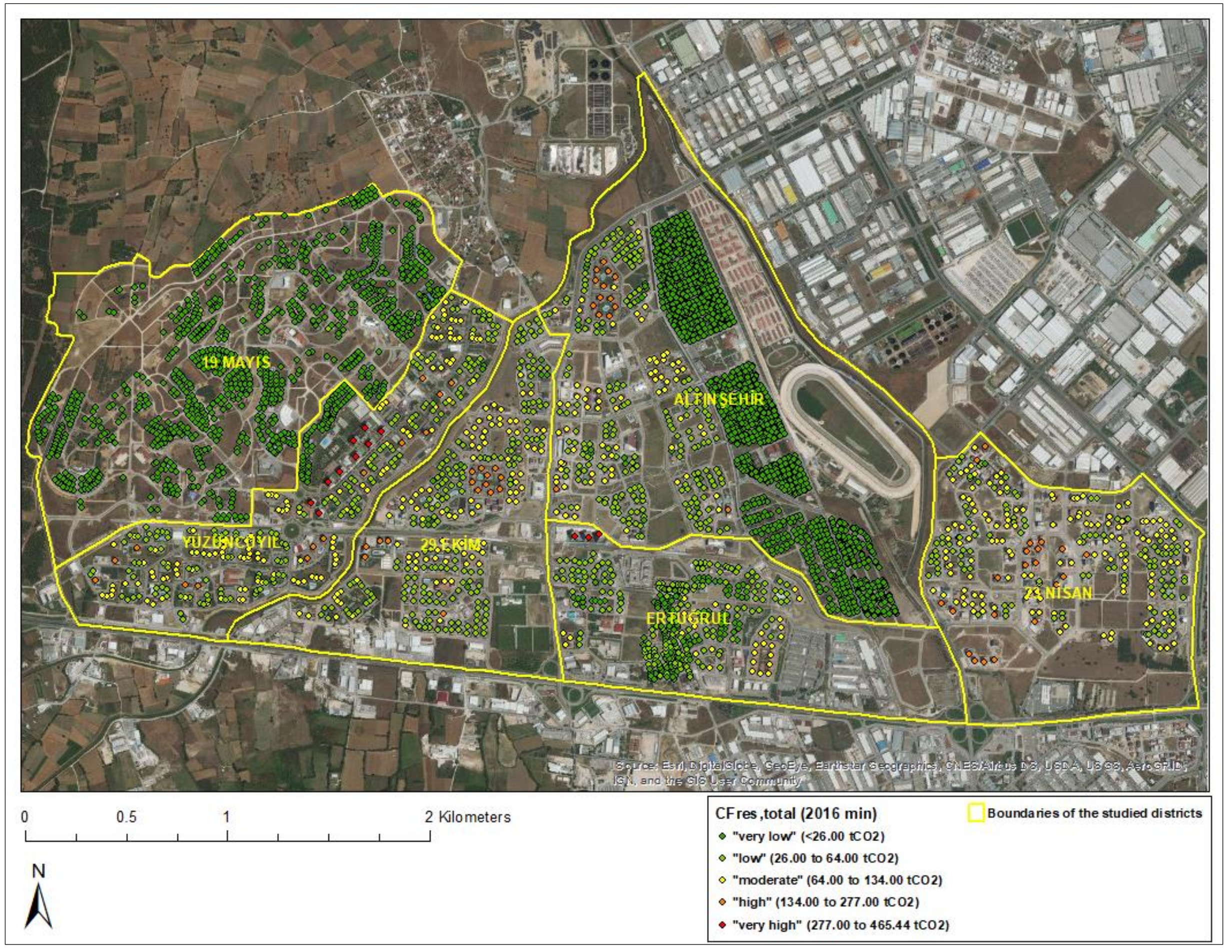


Figure 4-9. Classification of Customer Point Emissions for CFres,total (2016 min)

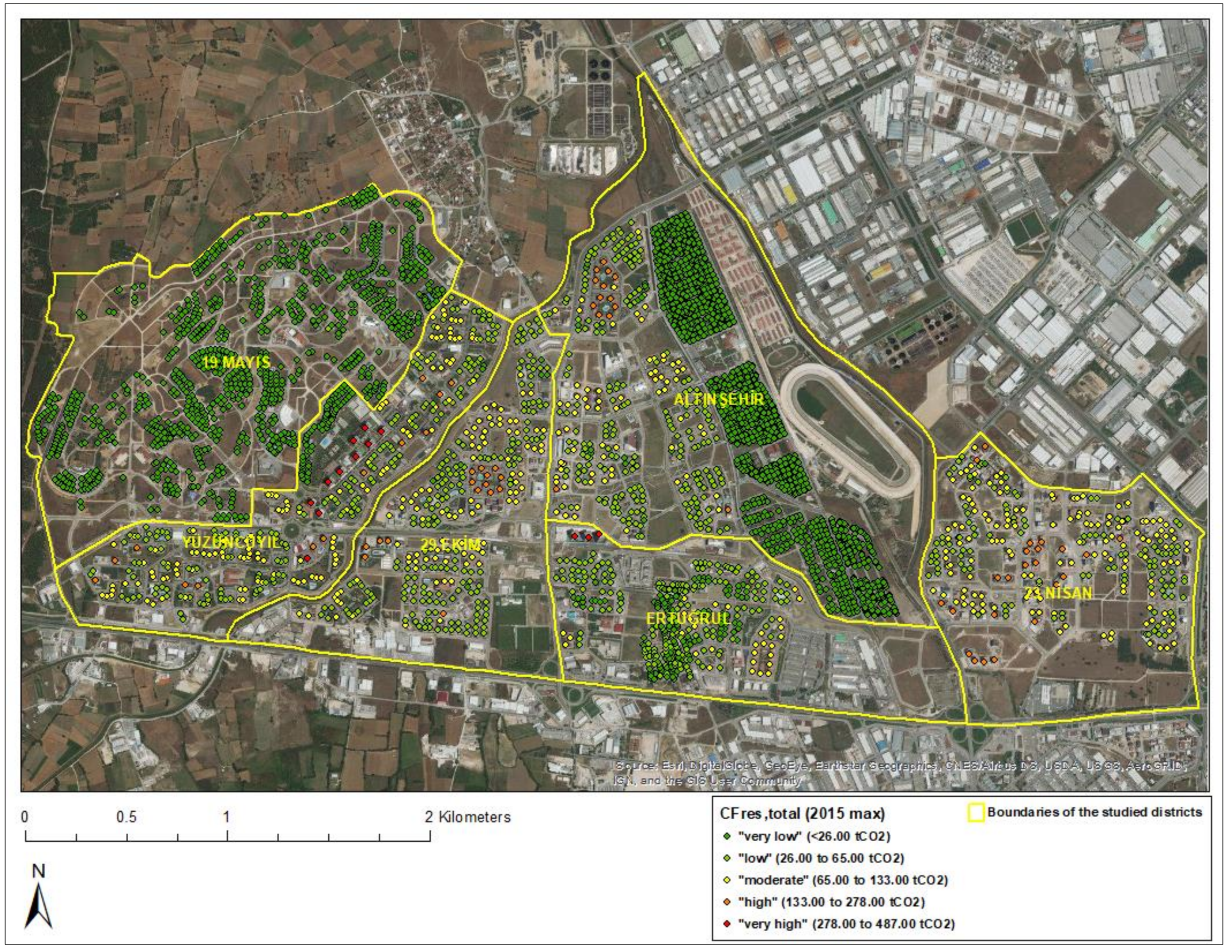


Figure 4-10. Classification of Customer Point Emissions for CFres,total (2015 max)

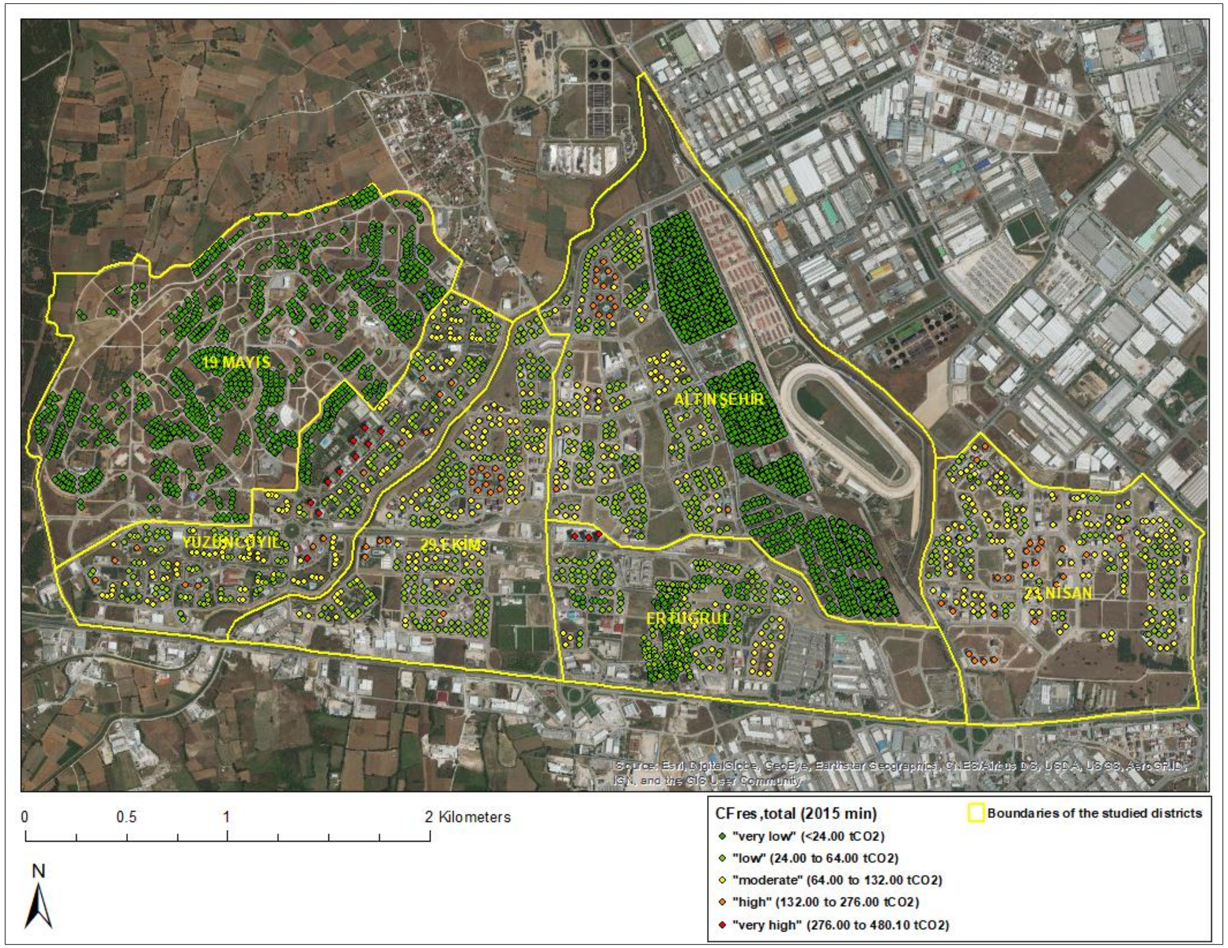


Figure 4-11. Classification of Customer Point Emissions for CFres,total (2015 min)

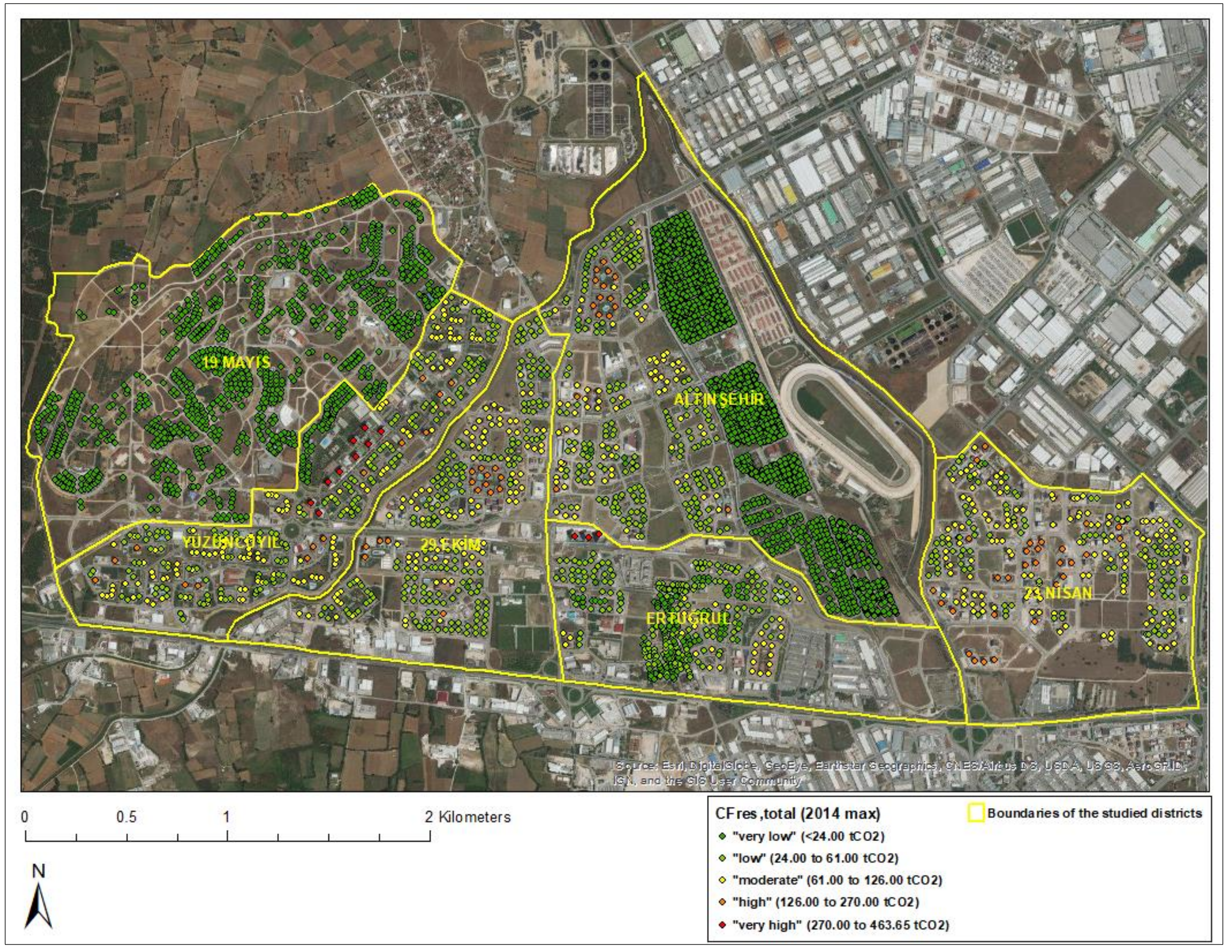


Figure 4-12. Classification of Customer Point Emissions for CFres,total (2014 max)

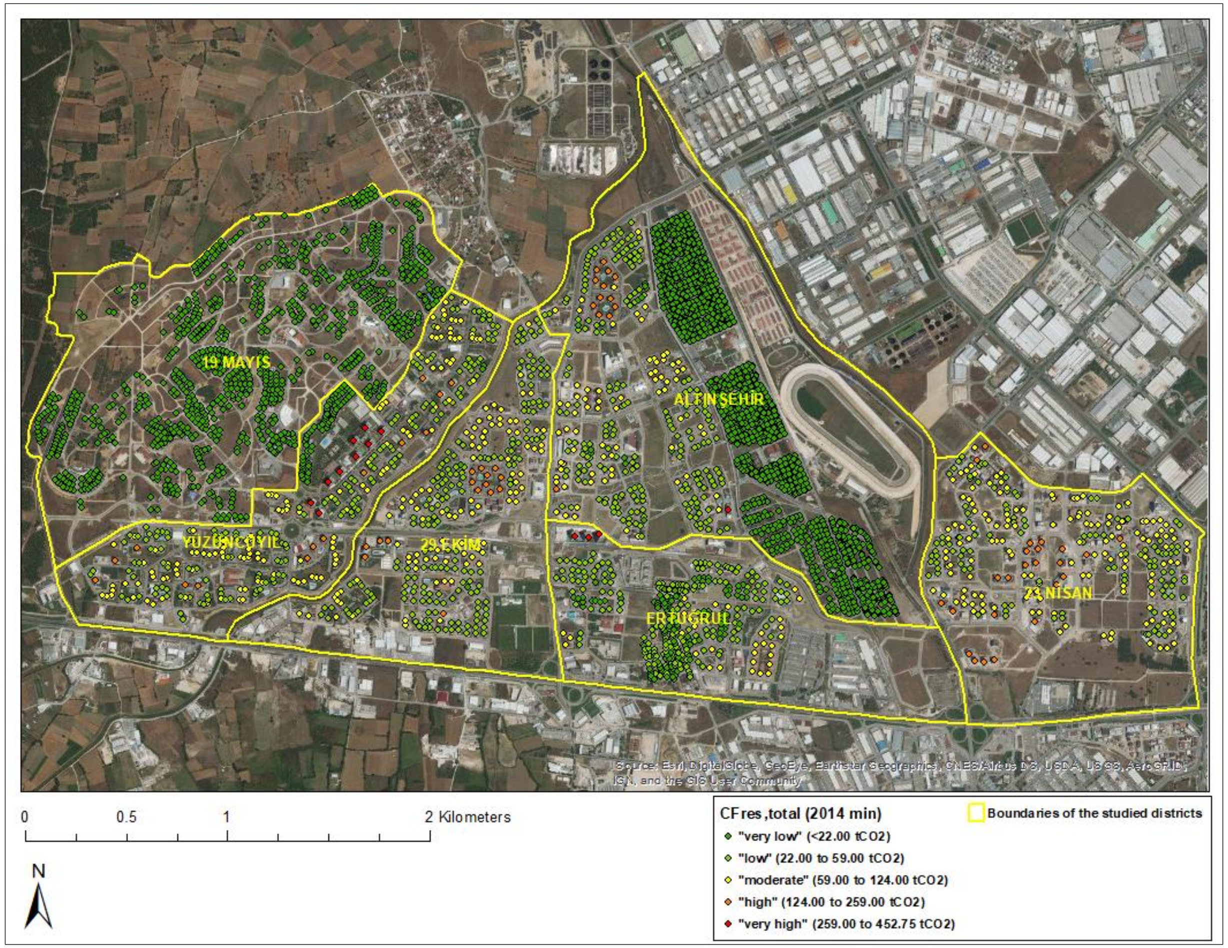


Figure 4-13. Classification of Customer Point Emissions for CFres,total (2014 min)

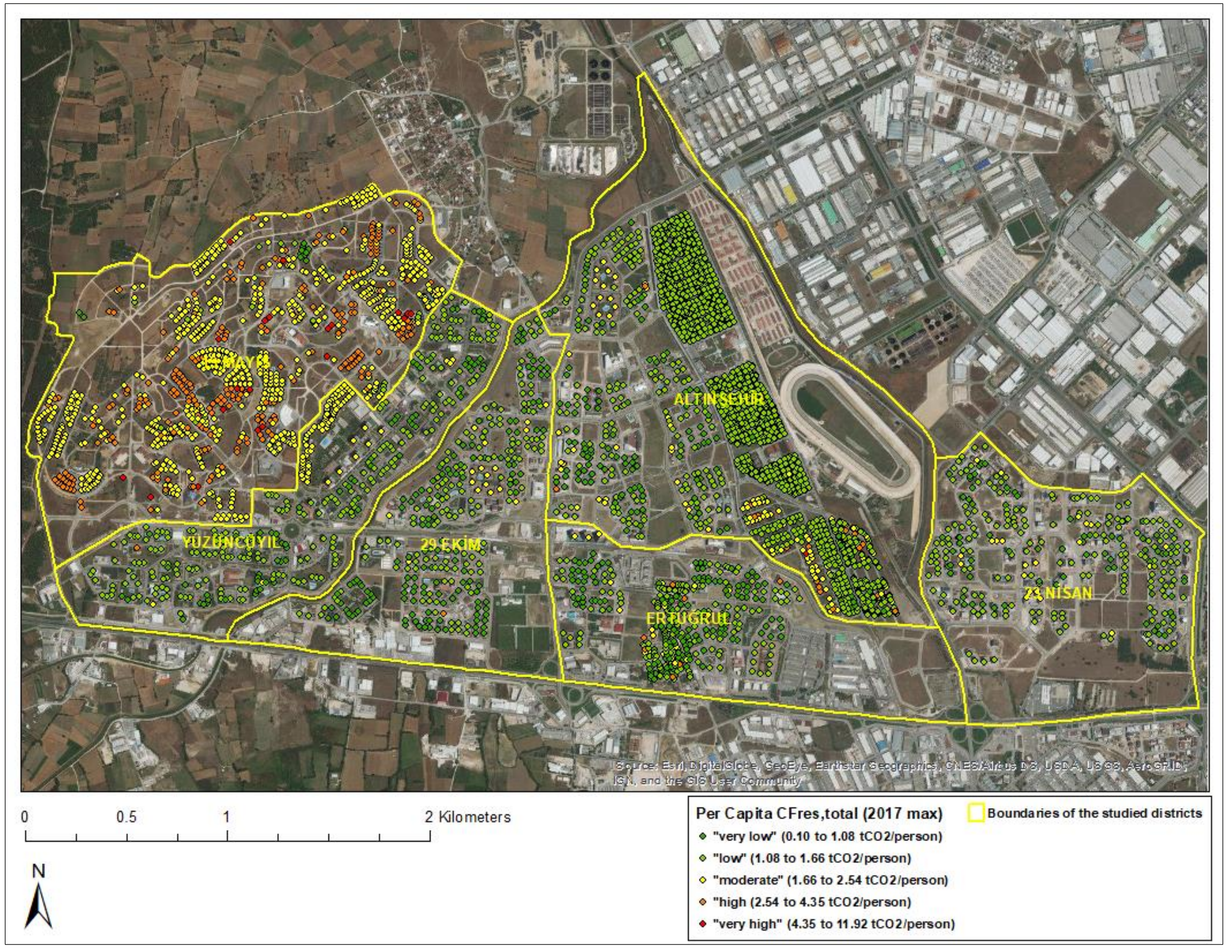


Figure 4-14. Classification of Customer Point Emissions for Per Capita CFres,total (2017 max)

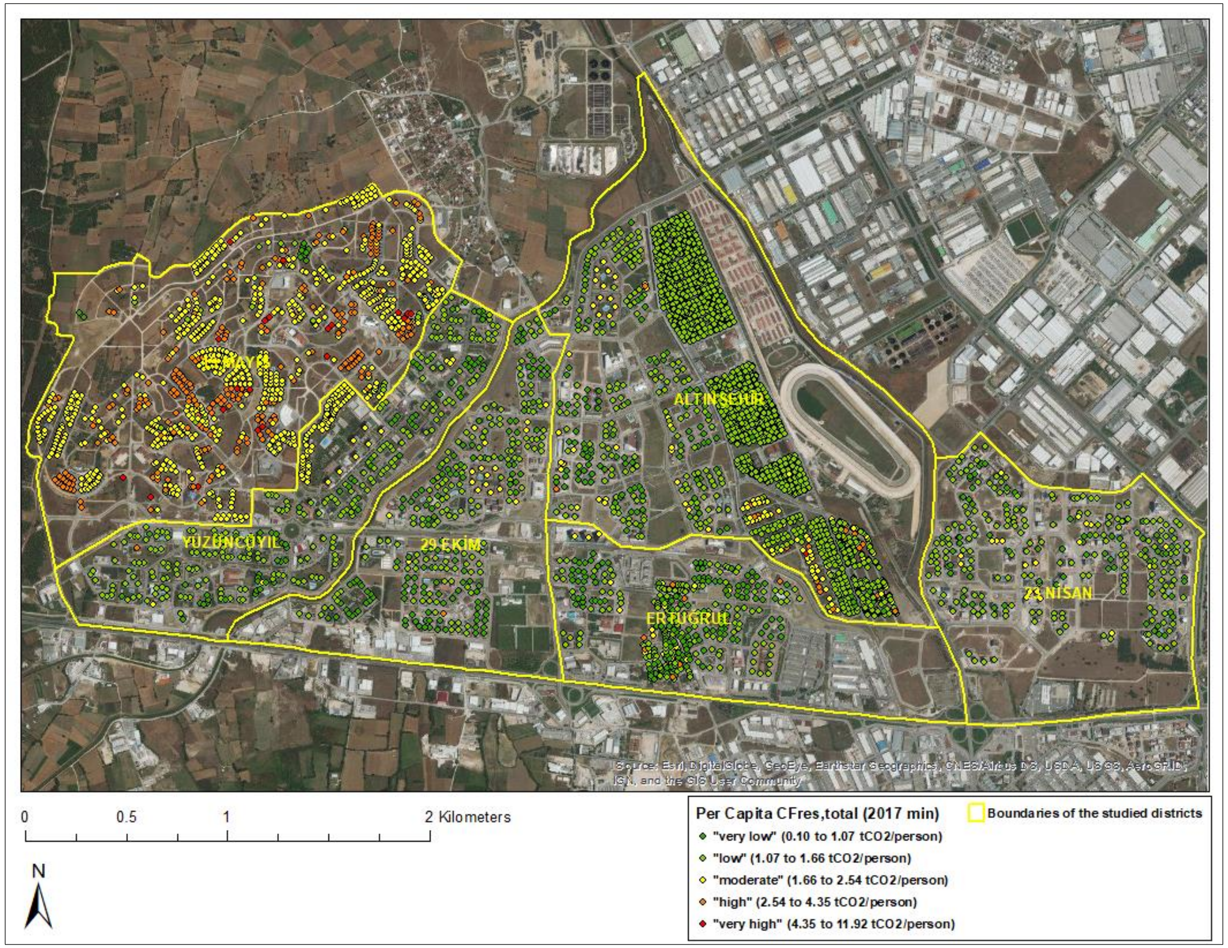


Figure 4-15. Classification of Customer Point Emissions for Per Capita CFres,total (2017 min)

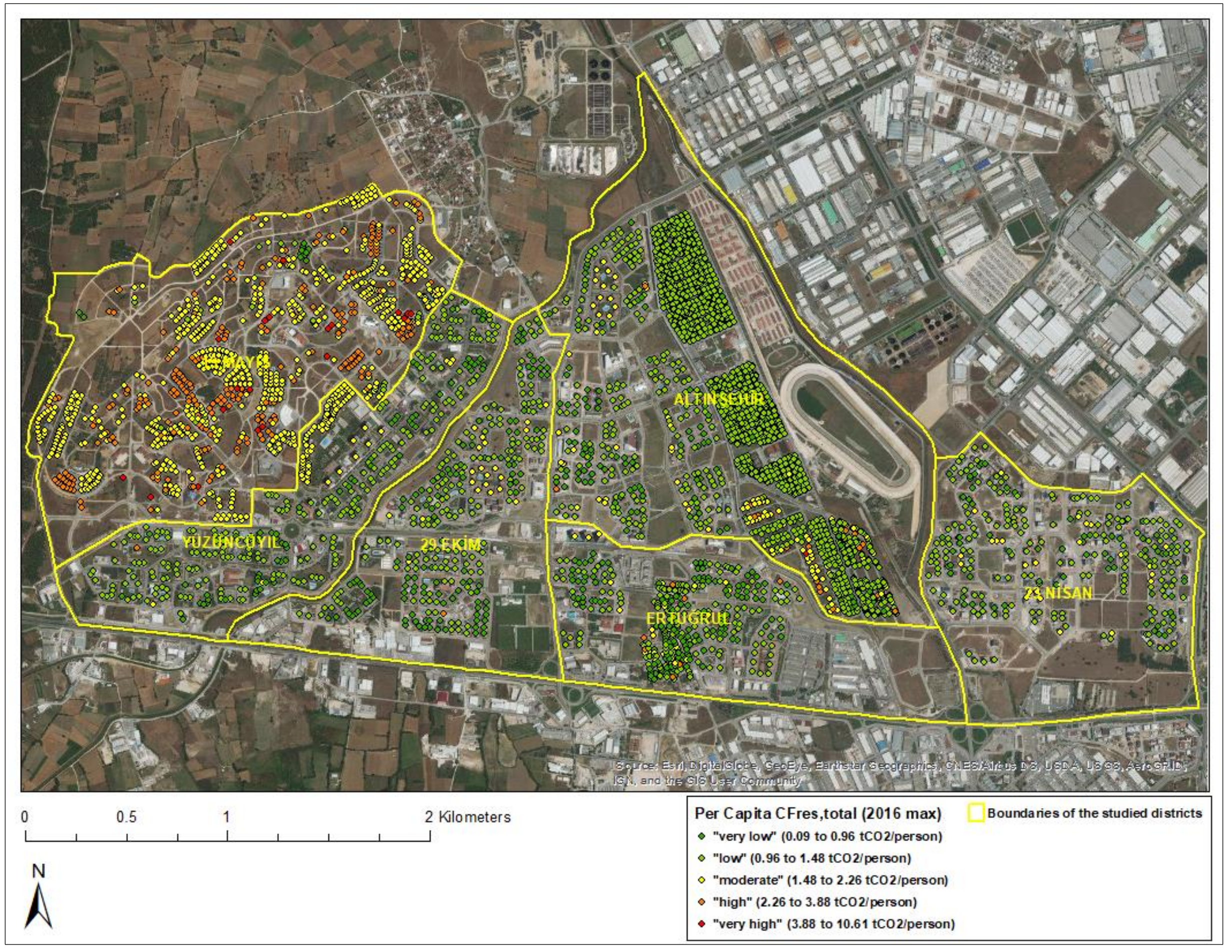


Figure 4-16. Classification of Customer Point Emissions for Per Capita CFres,total (2016 max)

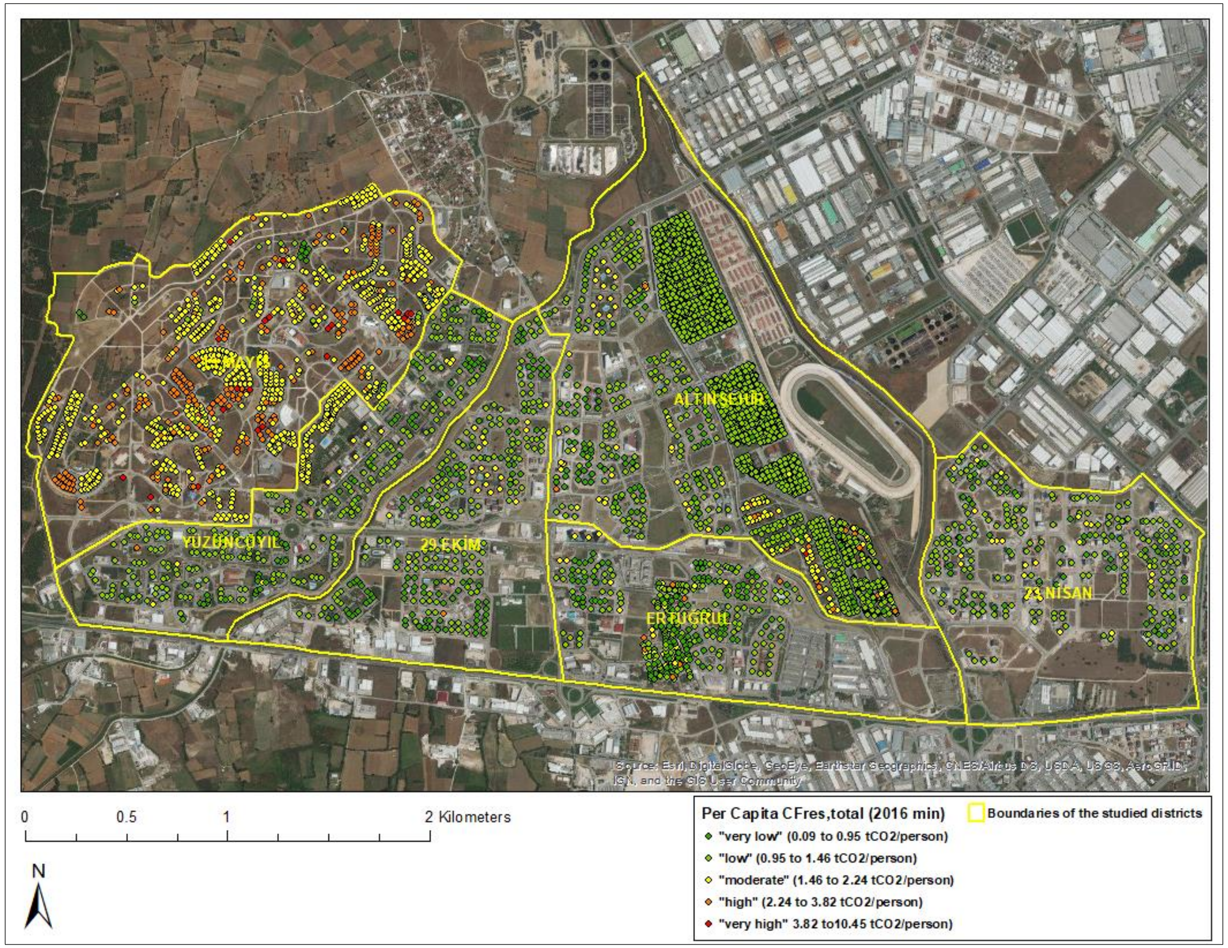


Figure 4-17. Classification of Customer Point Emissions for Per Capita CFres,total (2016 min)

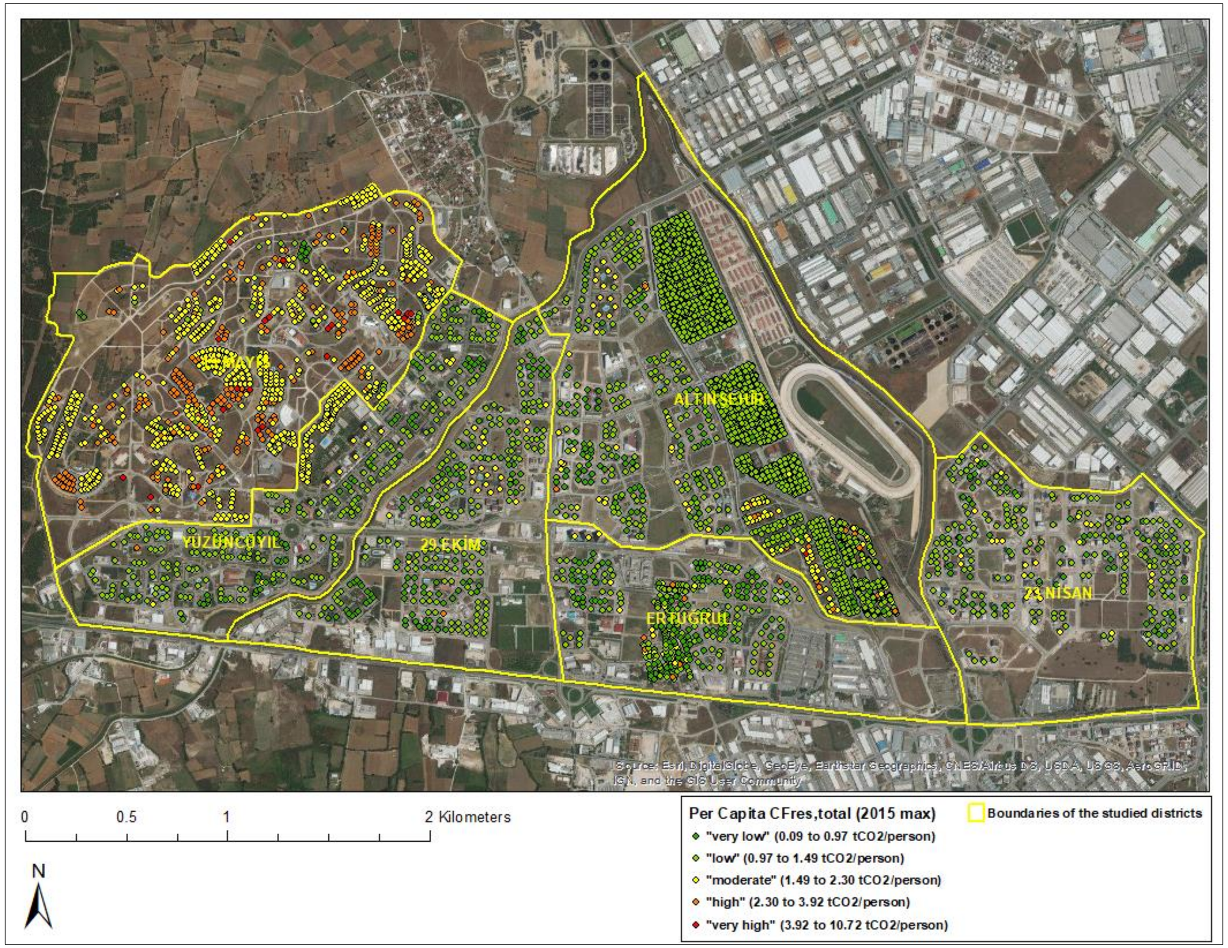


Figure 4-18. Classification of Customer Point Emissions for Per Capita CFres,total (2015 max)

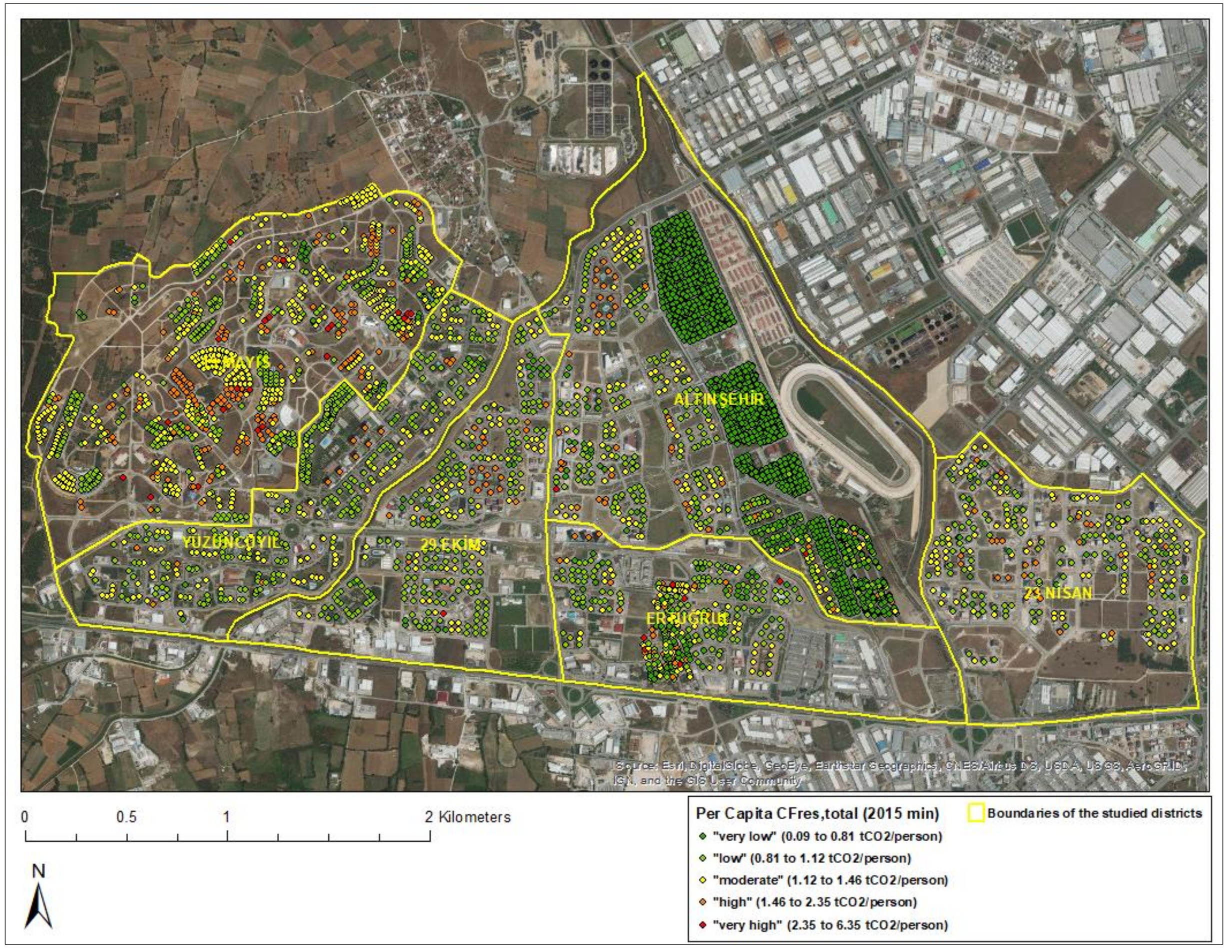


Figure 4-19. Classification of Customer Point Emissions for Per Capita CFres,total (2015 min)

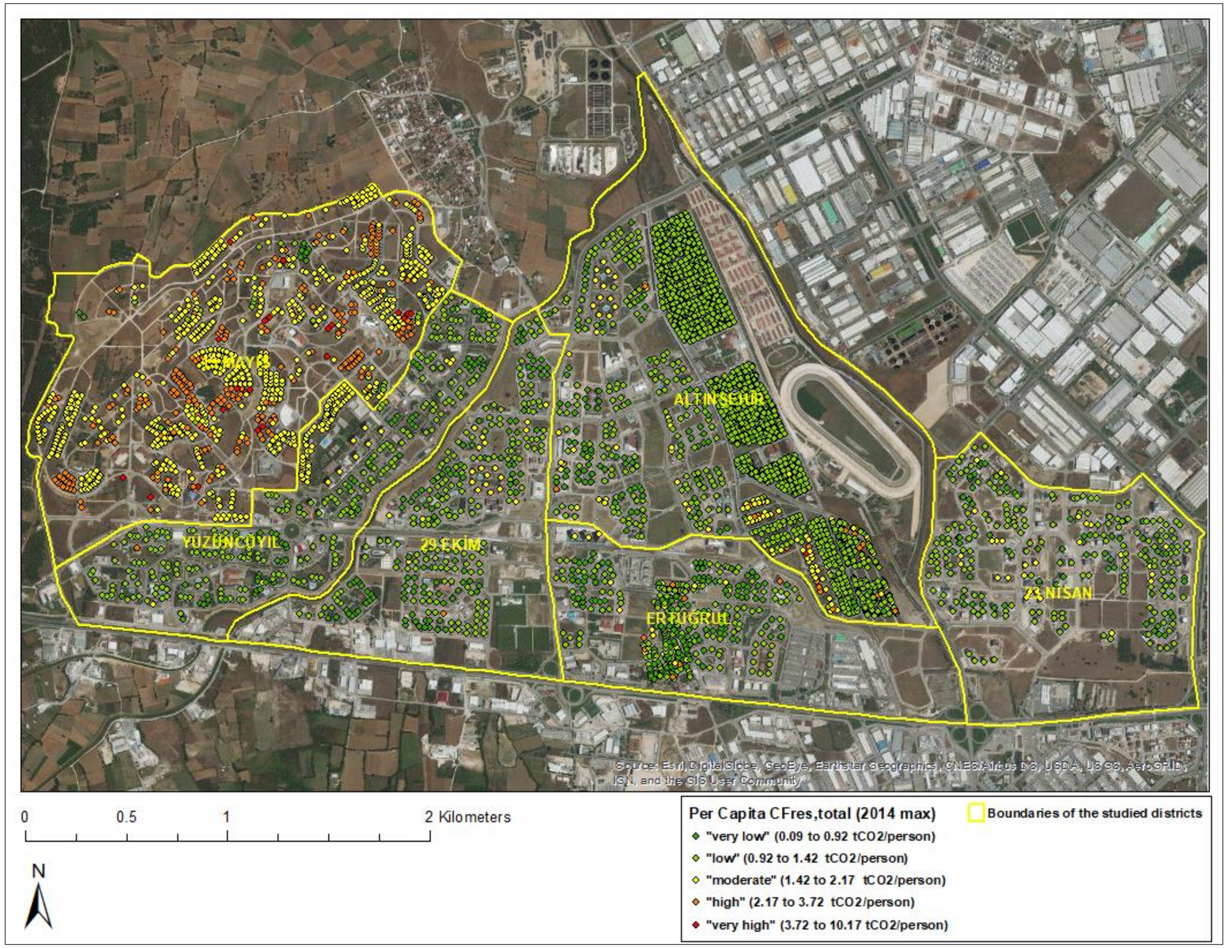


Figure 4-20. Classification of Customer Point Emissions for Per Capita CFres,total (2014 max)

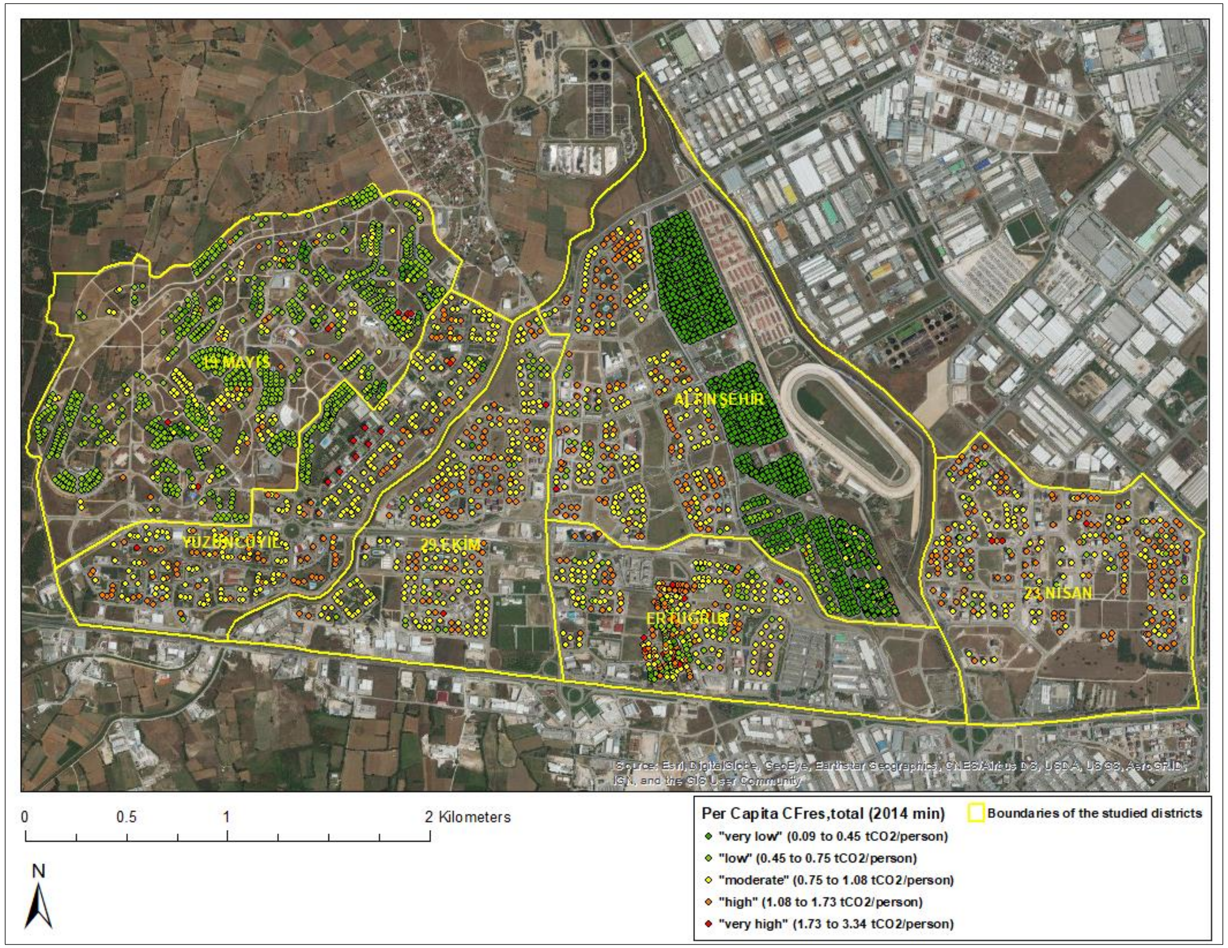
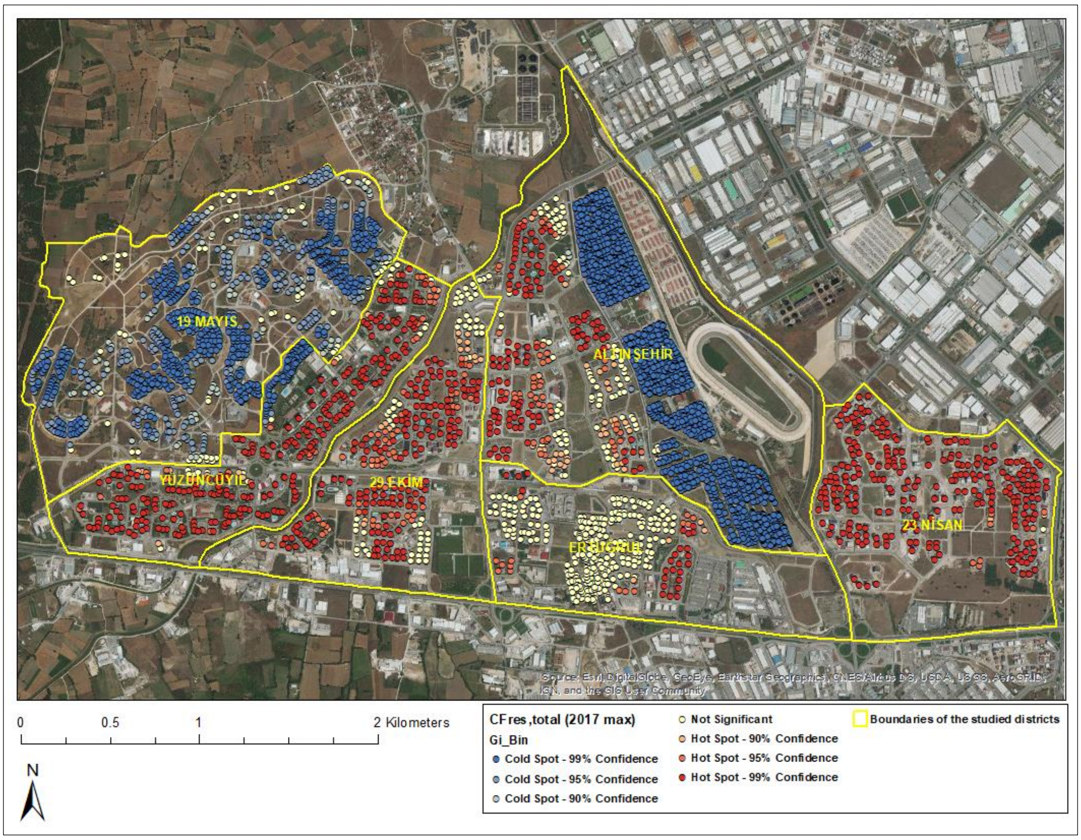


Figure 4-21. Classification of Customer Point Emissions for Per Capita CFres,total (2014 min)



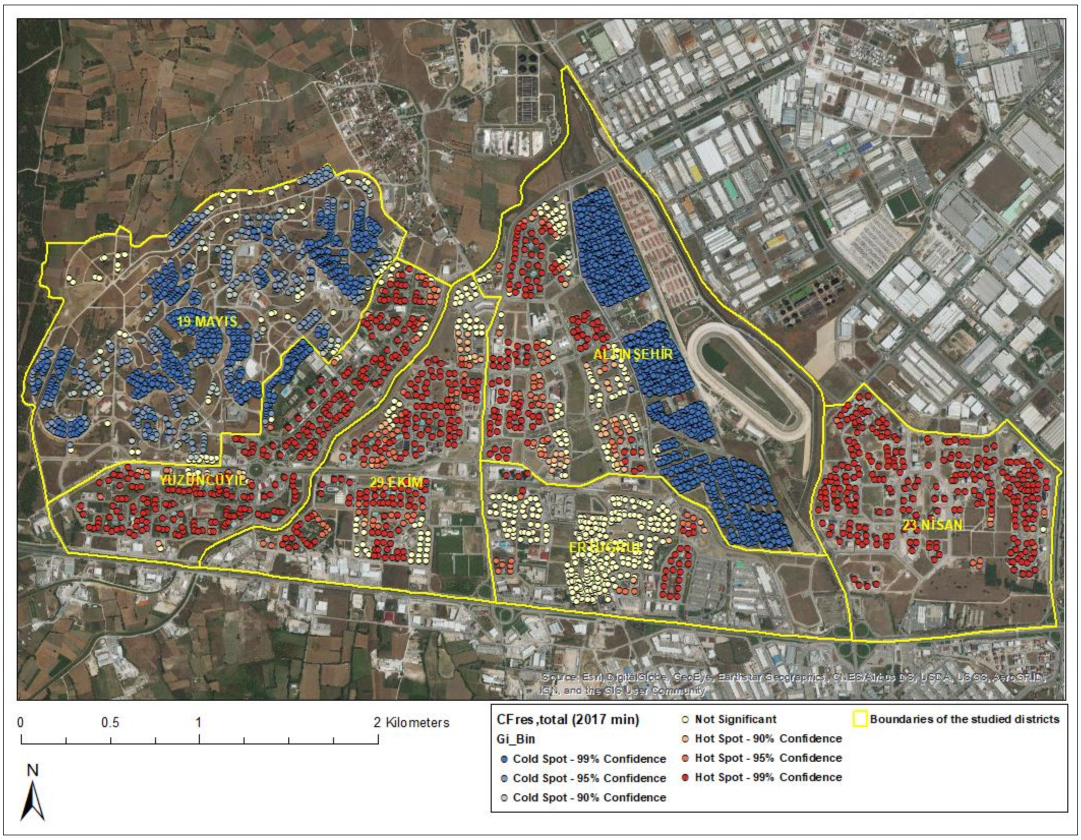


Figure 4-22. Hot Spot Analysis for CFres,total for 2017 max (top) and min (bottom)

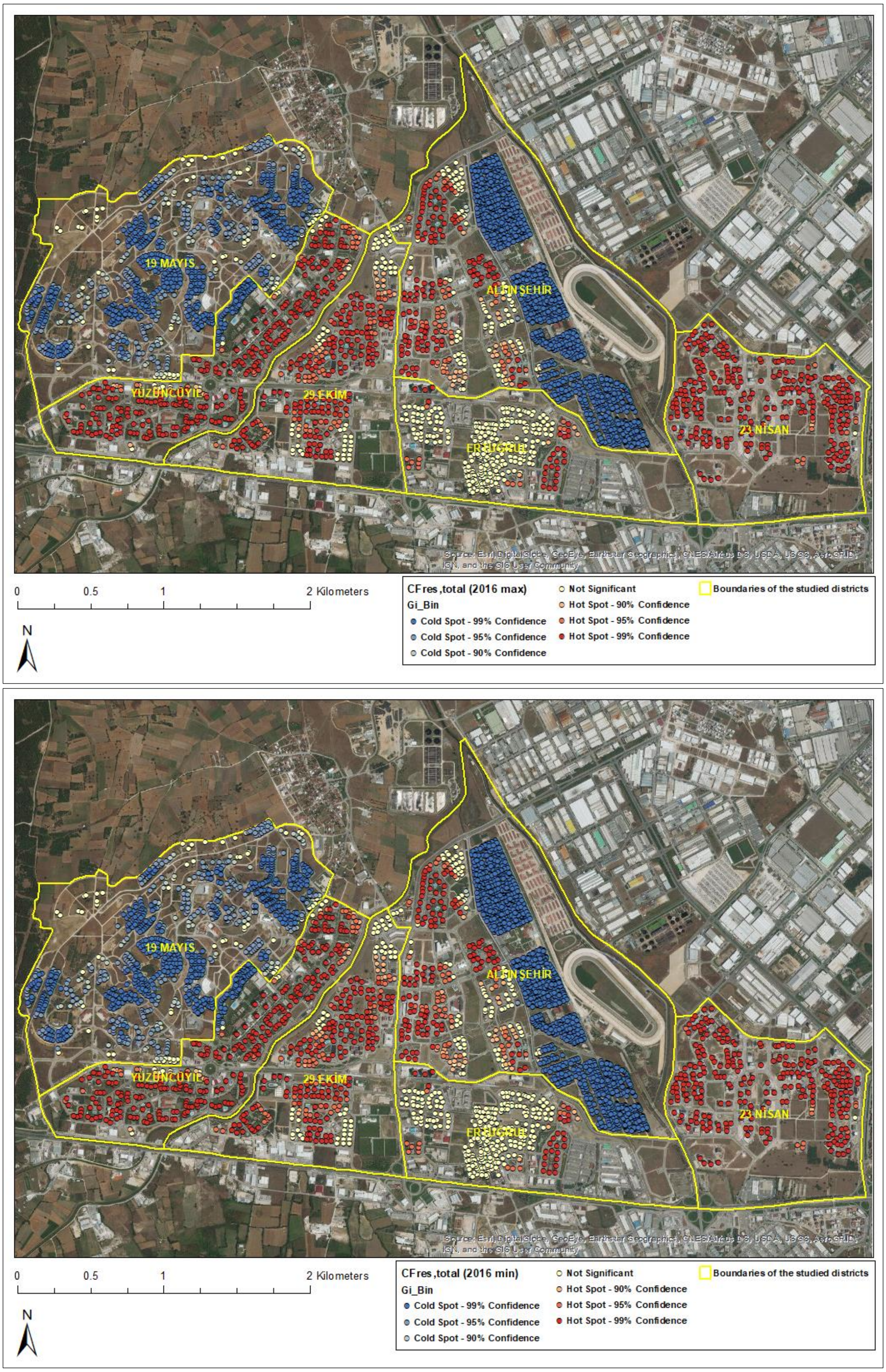


Figure 4-23. Hot Spot Analysis for CFres,total for 2016 max (top) and min (bottom)

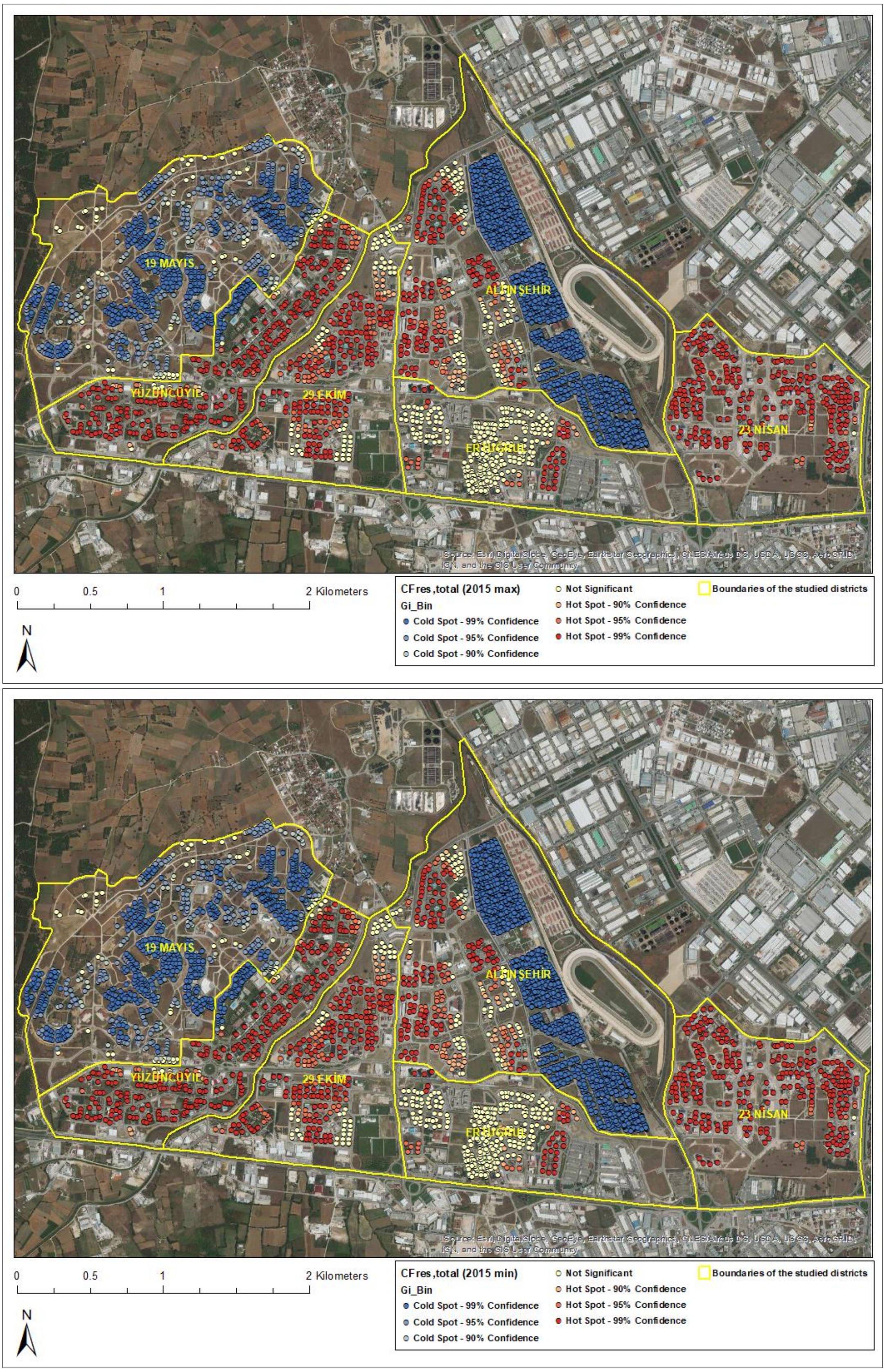
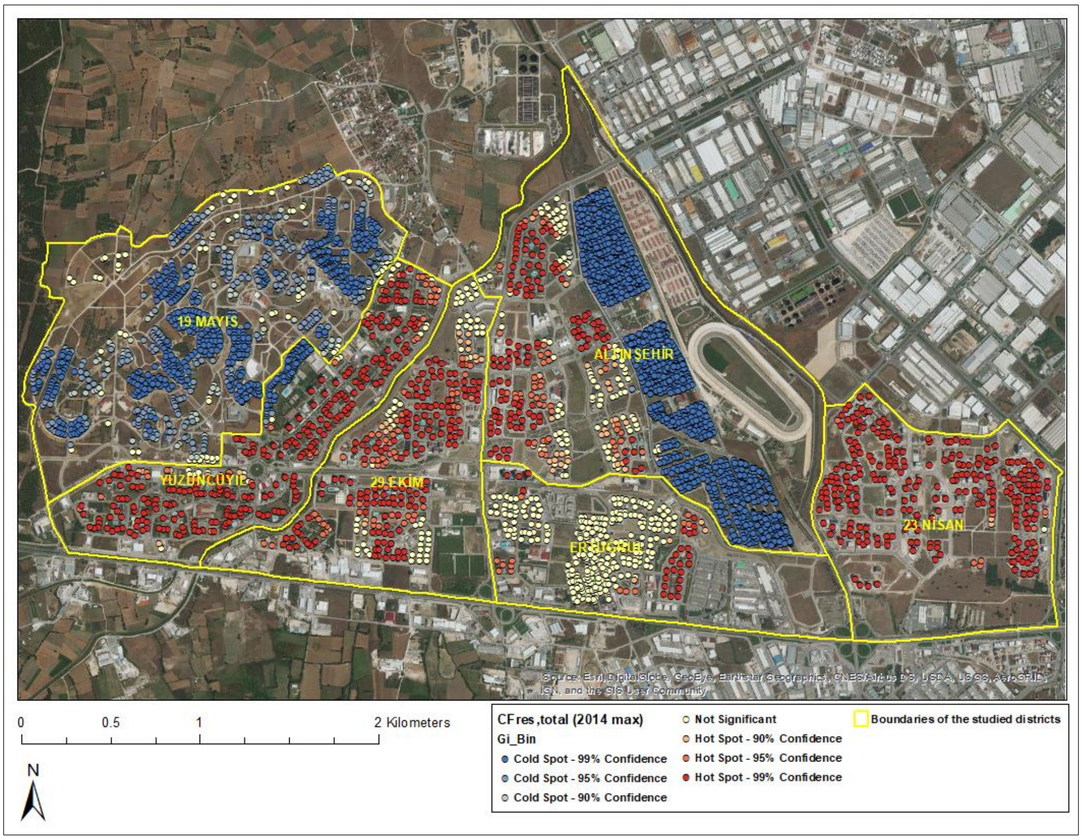


Figure 4-24. Hot Spot Analysis for CFres,total for 2015 max (top) and min (bottom)



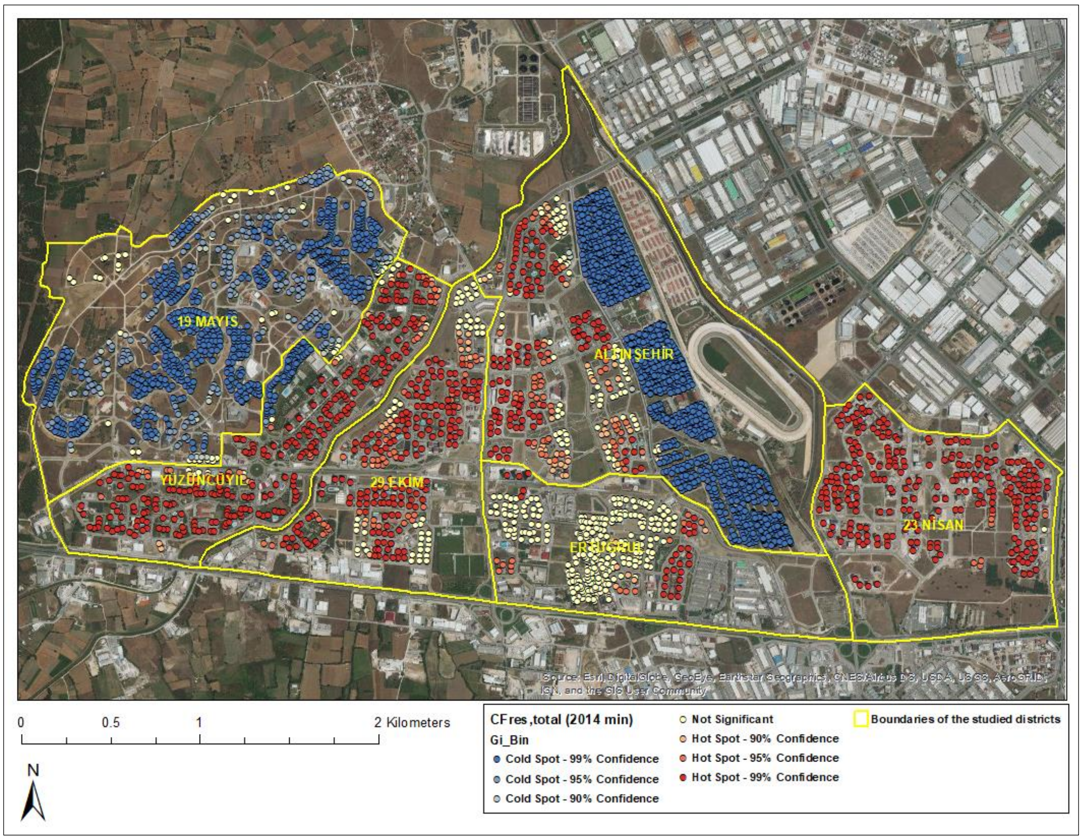


Figure 4-25. Hot Spot Analysis for CFres,total for 2014 max (top) and min (bottom)

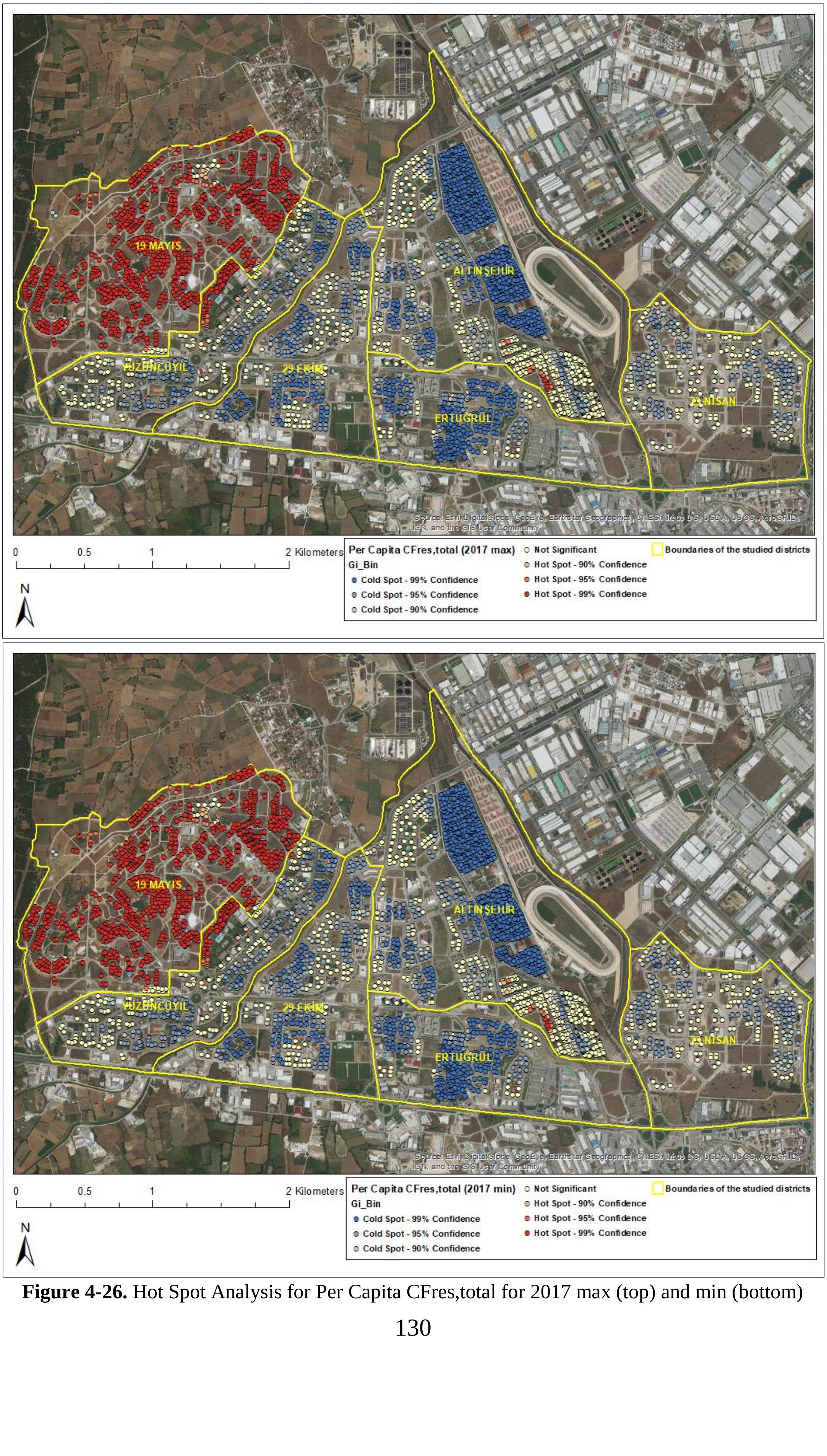
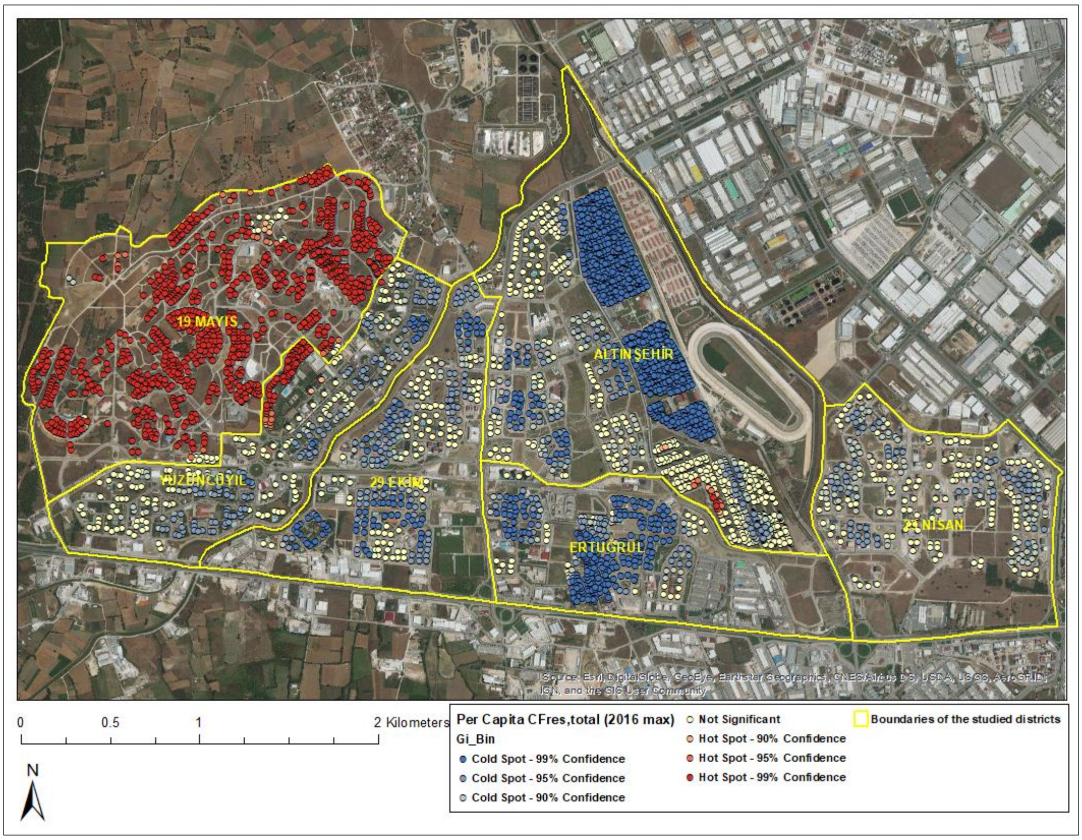


Figure 4-26. Hot Spot Analysis for Per Capita CFres,total for 2017 max (top) and min (bottom)



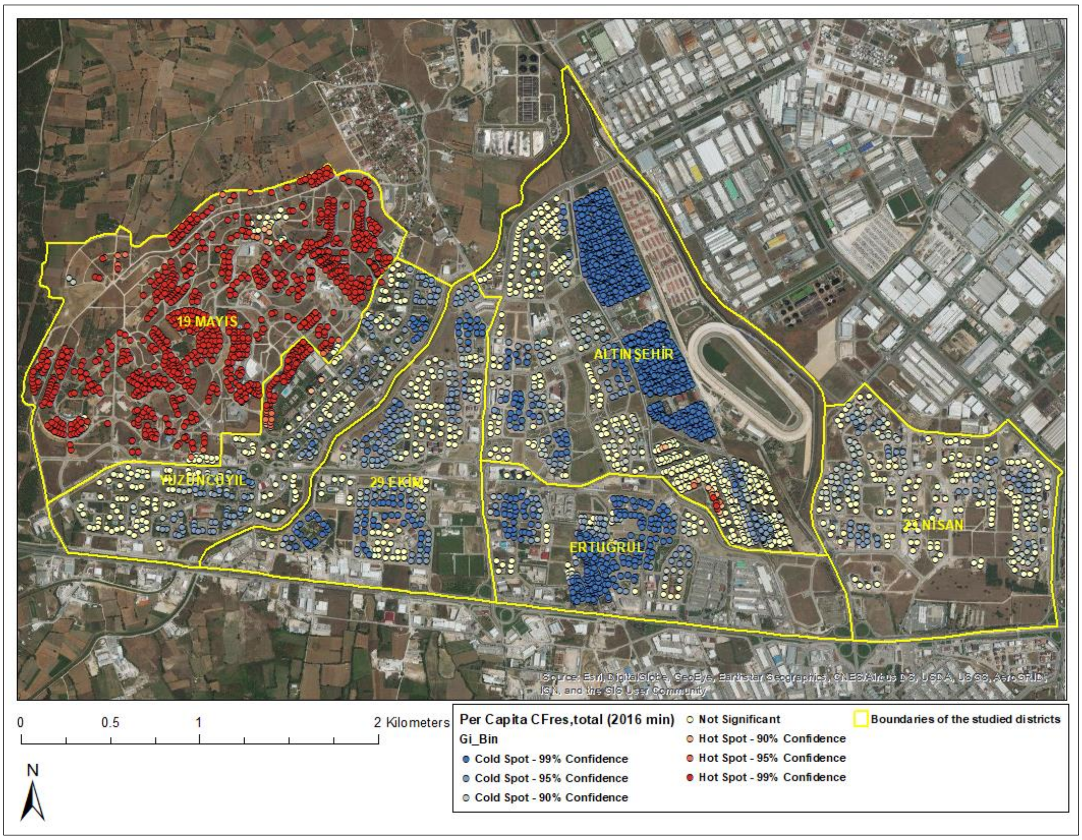
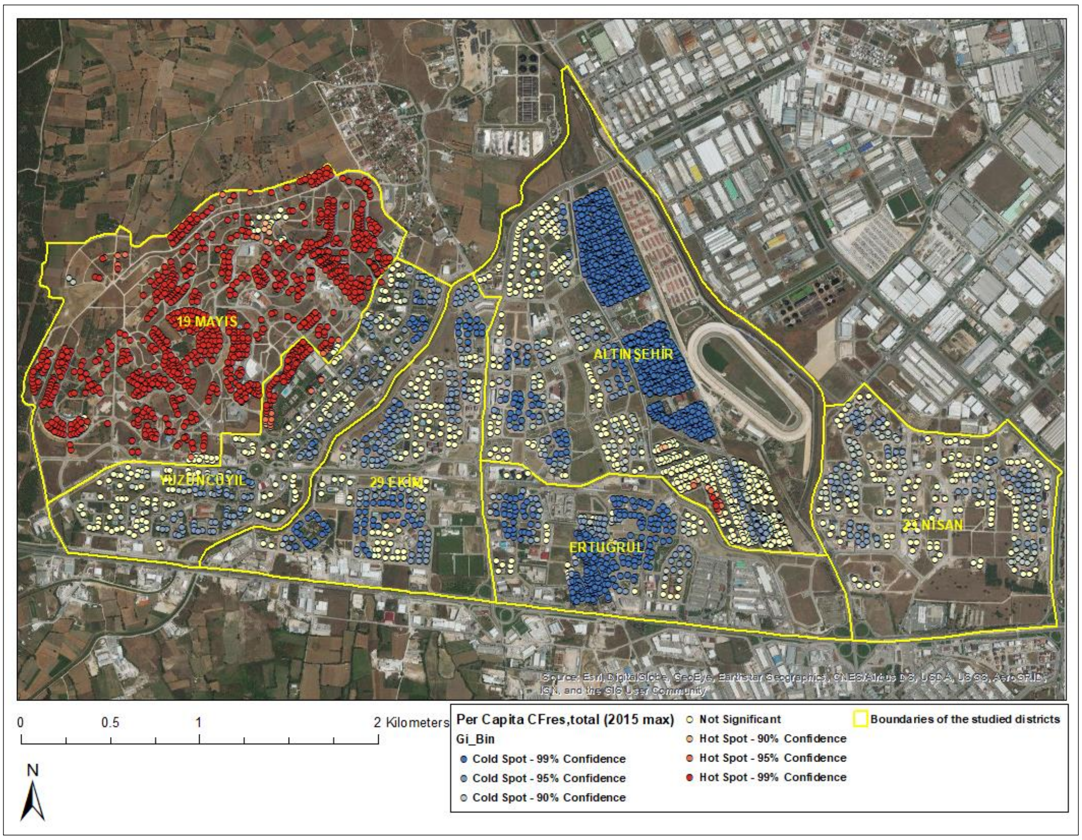


Figure 4-27. Hot Spot Analysis for Per Capita CFres,total for 2016 max (top) and min (bottom)



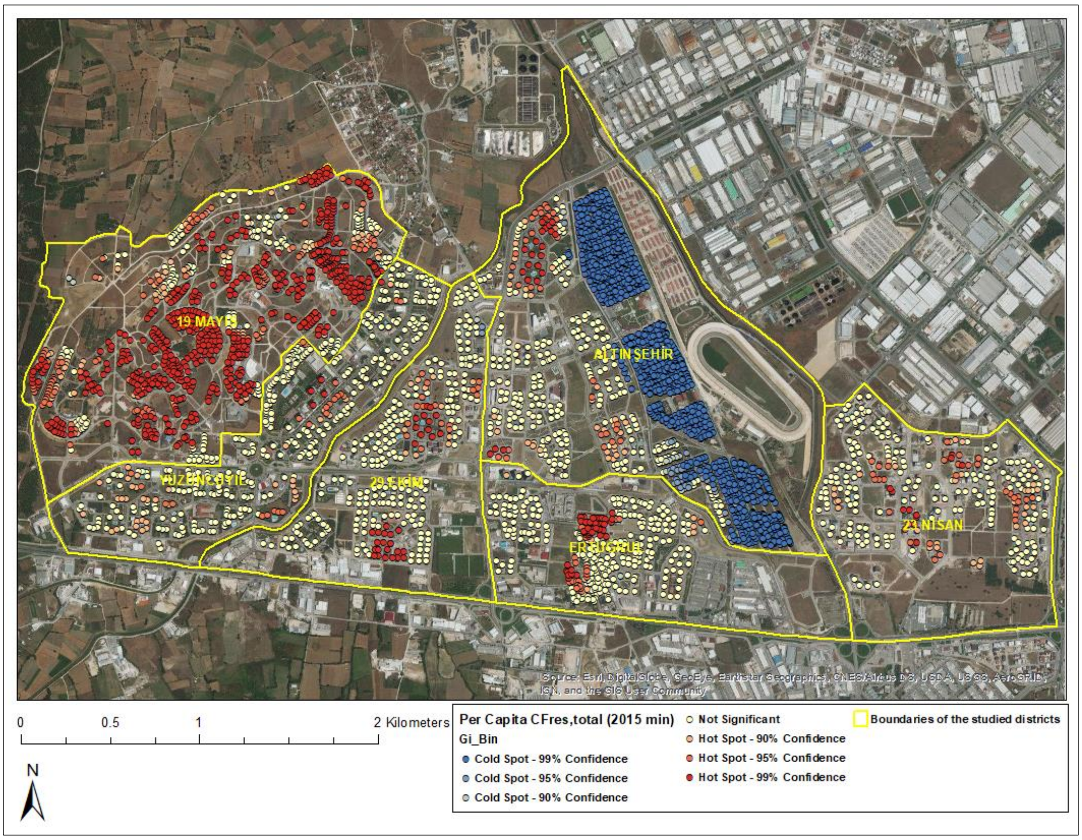


Figure 4-28. Hot Spot Analysis for Per Capita CFres,total for 2015 max (top) and min (bottom)

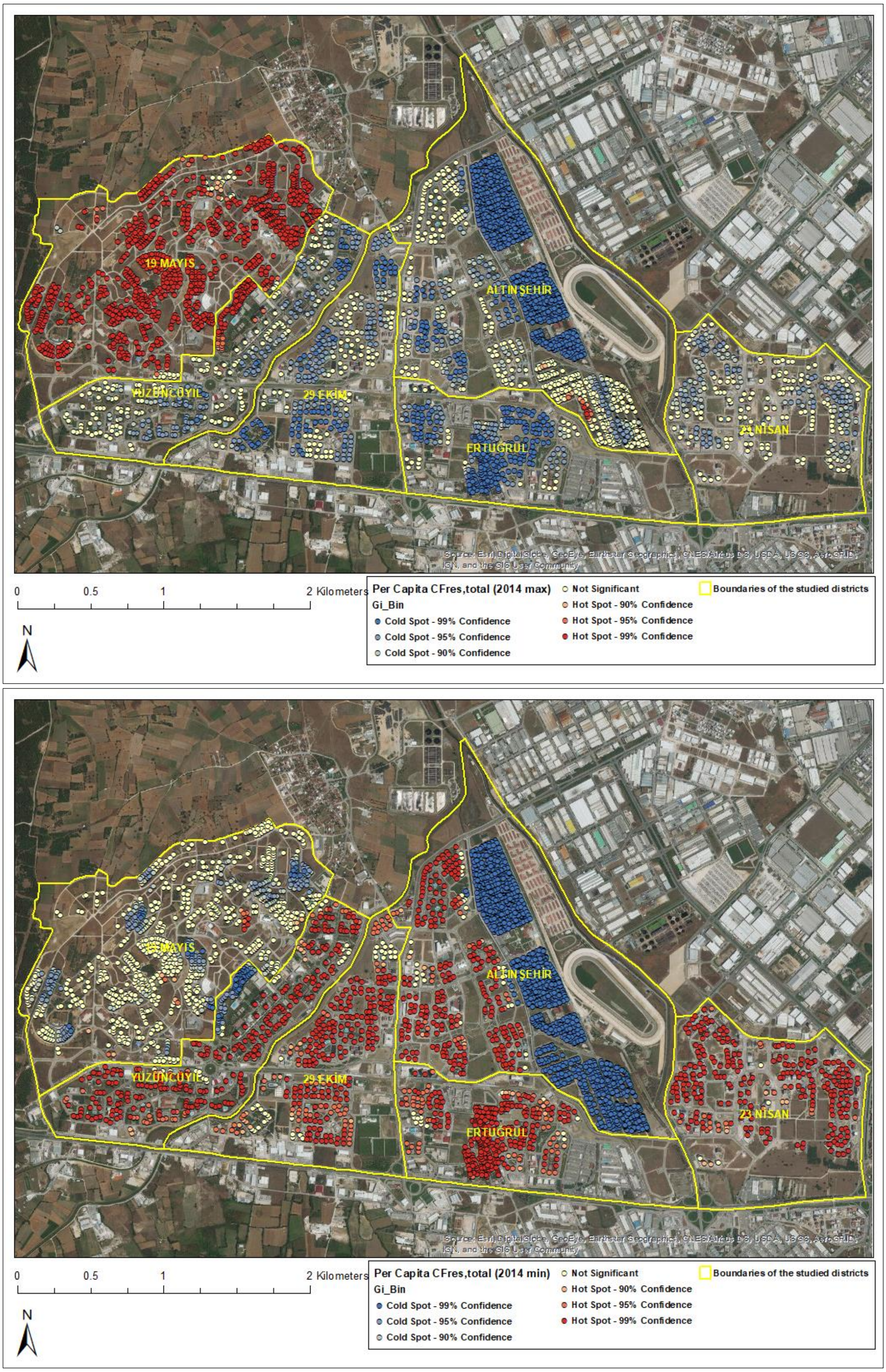


Figure 4-29. Hot Spot Analysis for Per Capita CFres,total for 2014 max (top) and min (bottom)

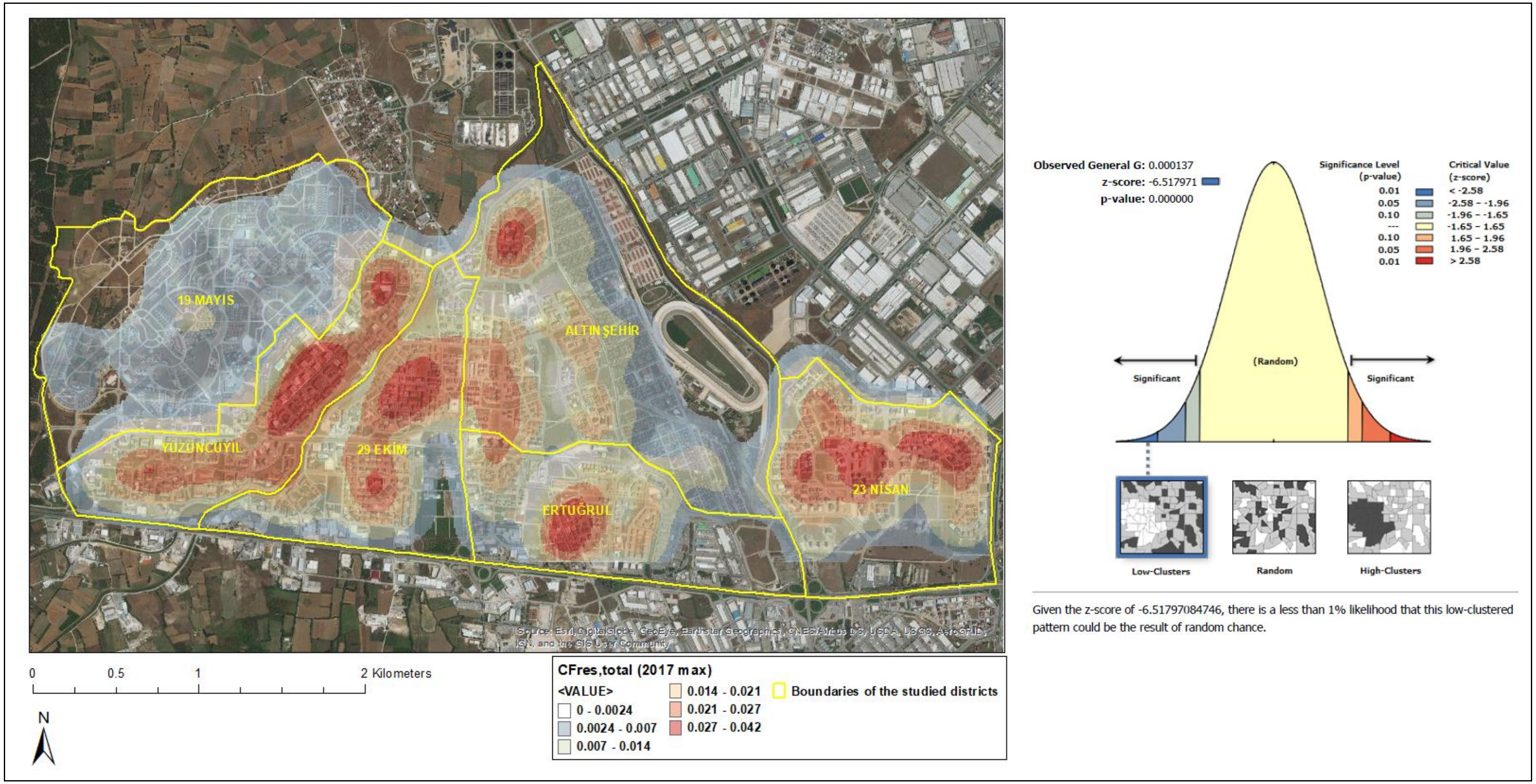


Figure 4-30. Kernel Density Map for CFres,total (2017 max)

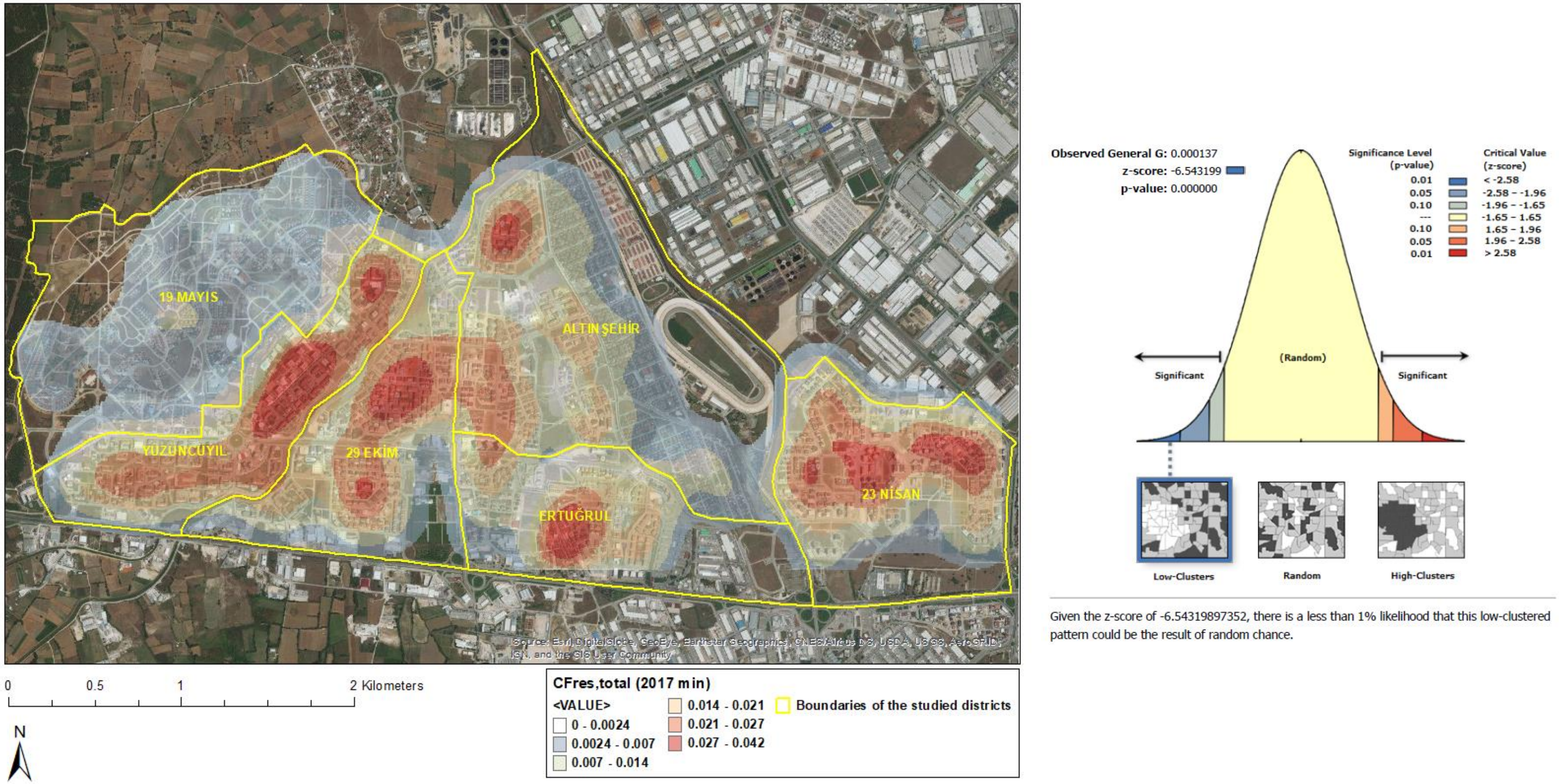


Figure 4-31. Kernel Density Map for CFres,total (2017 min)

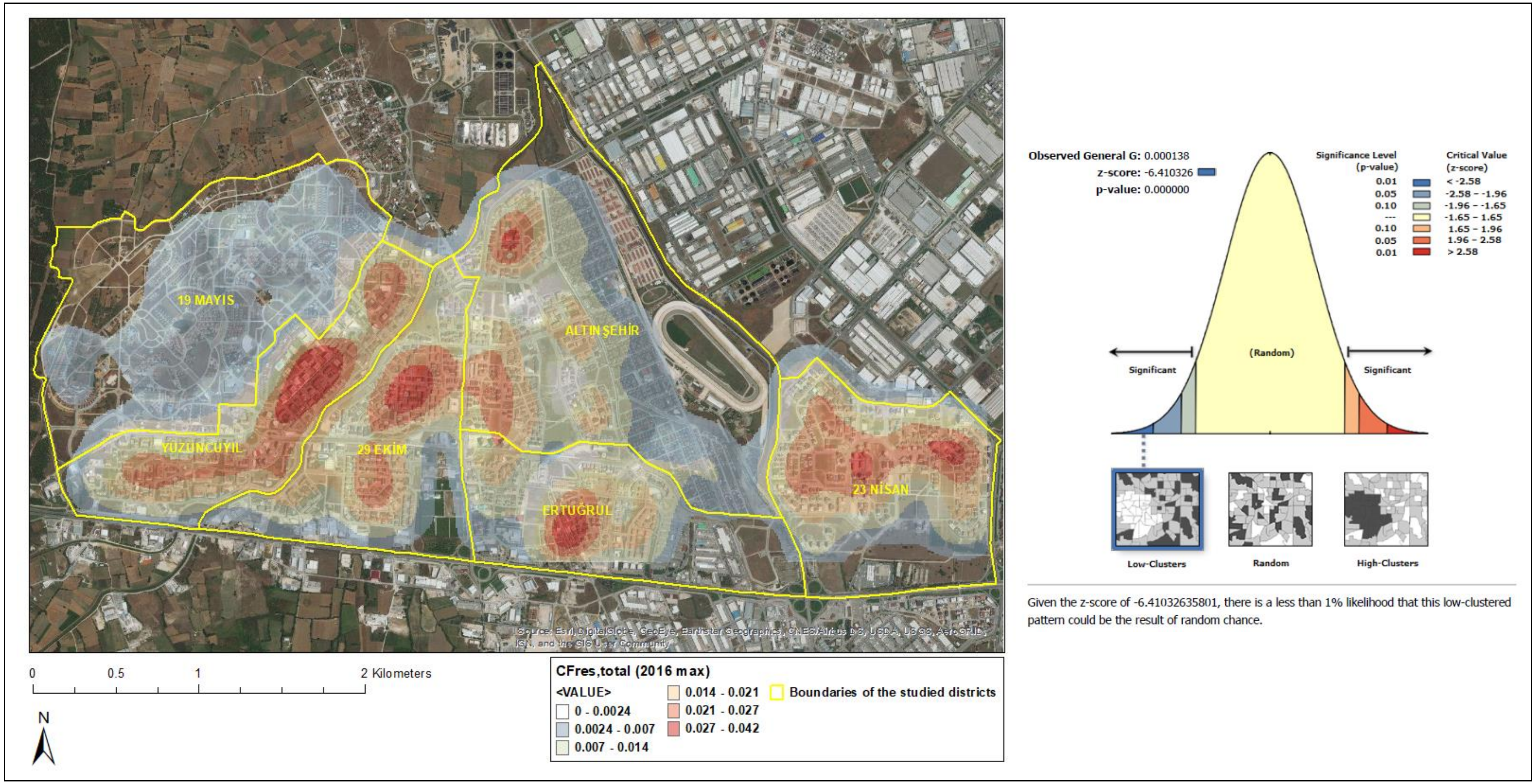


Figure 4-32. Kernel Density Map for CFres,total (2016 max)

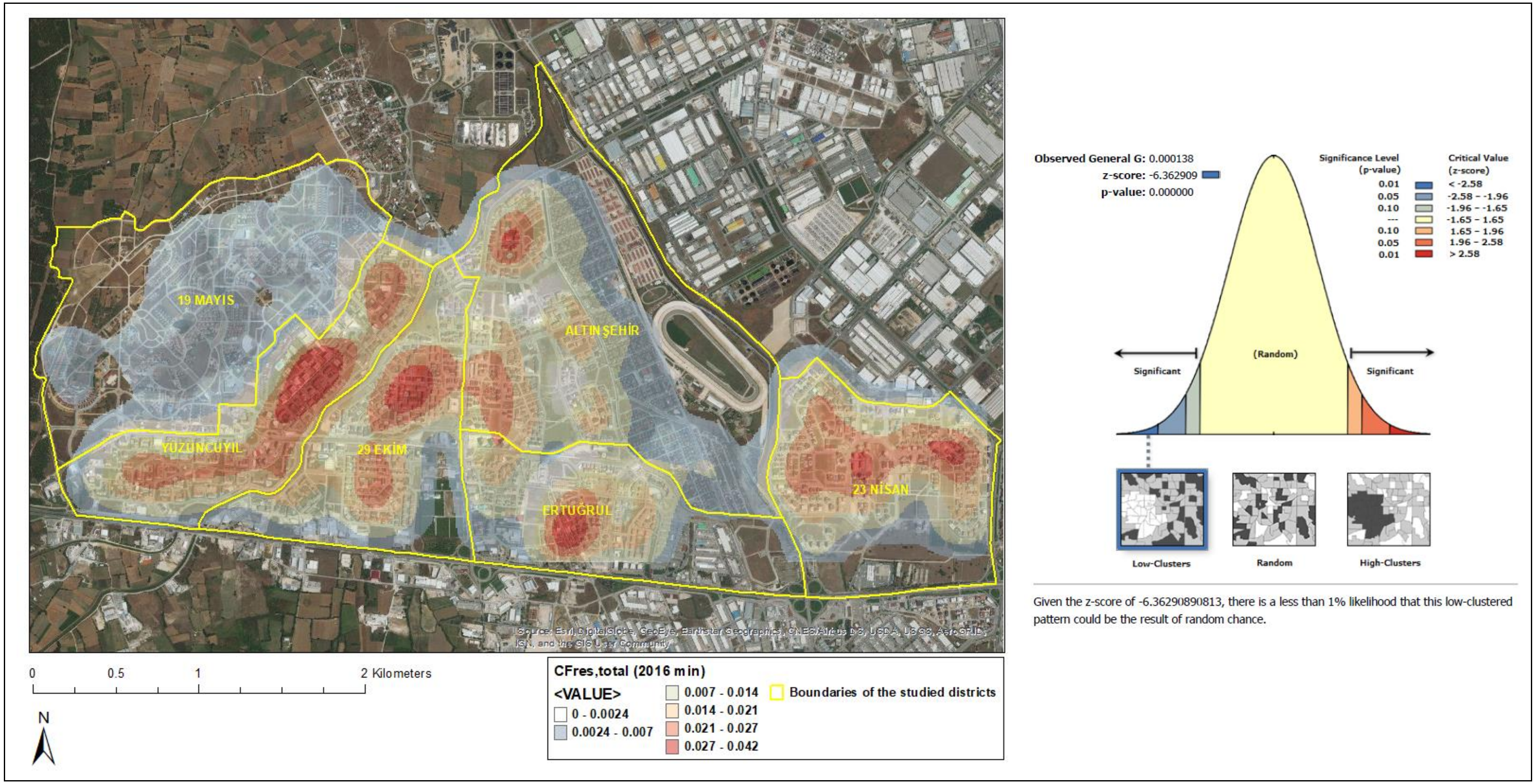


Figure 4-33. Kernel Density Map for CFres,total (2016 min)

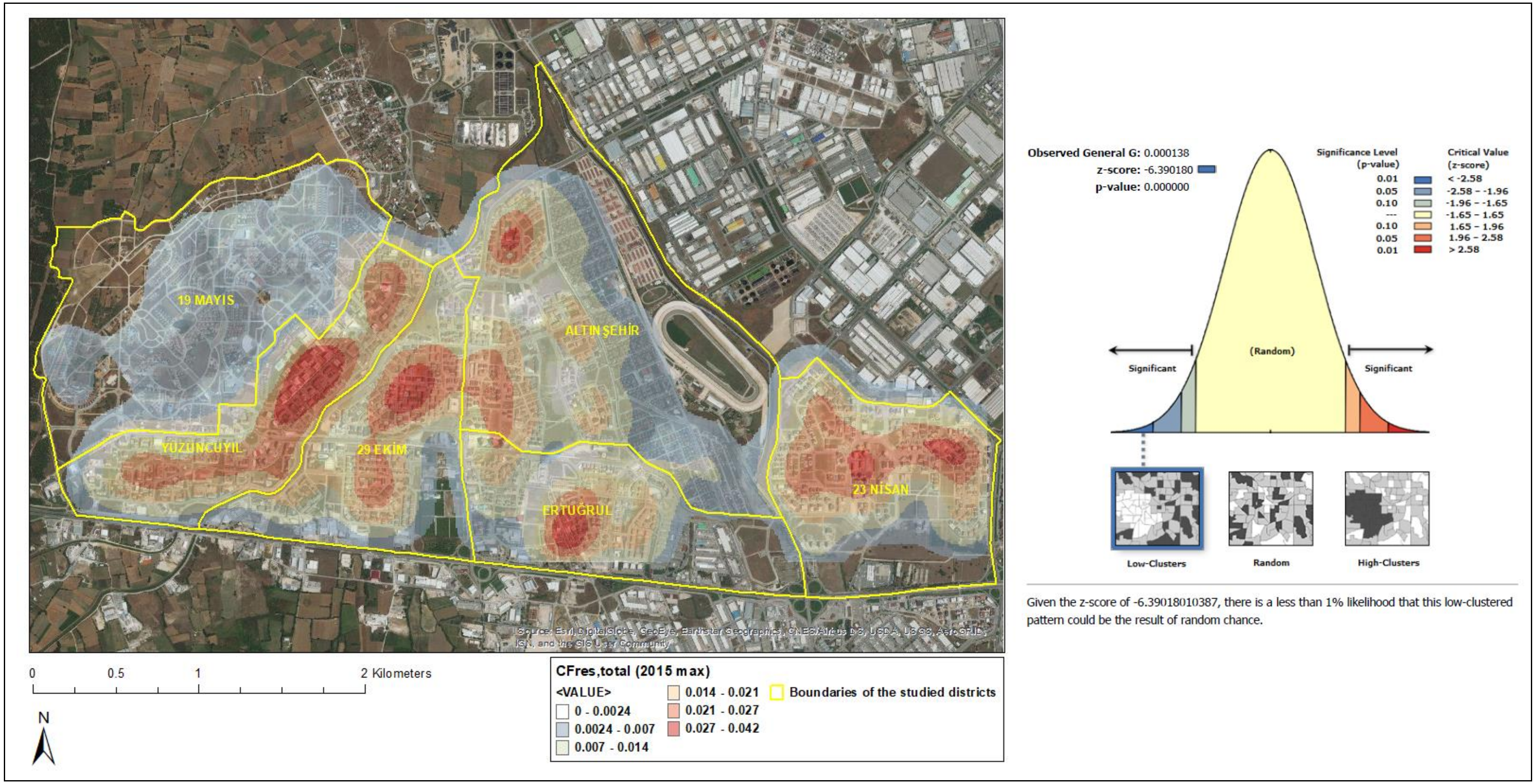


Figure 4-34. Kernel Density Map for CFres,total (2015 max)

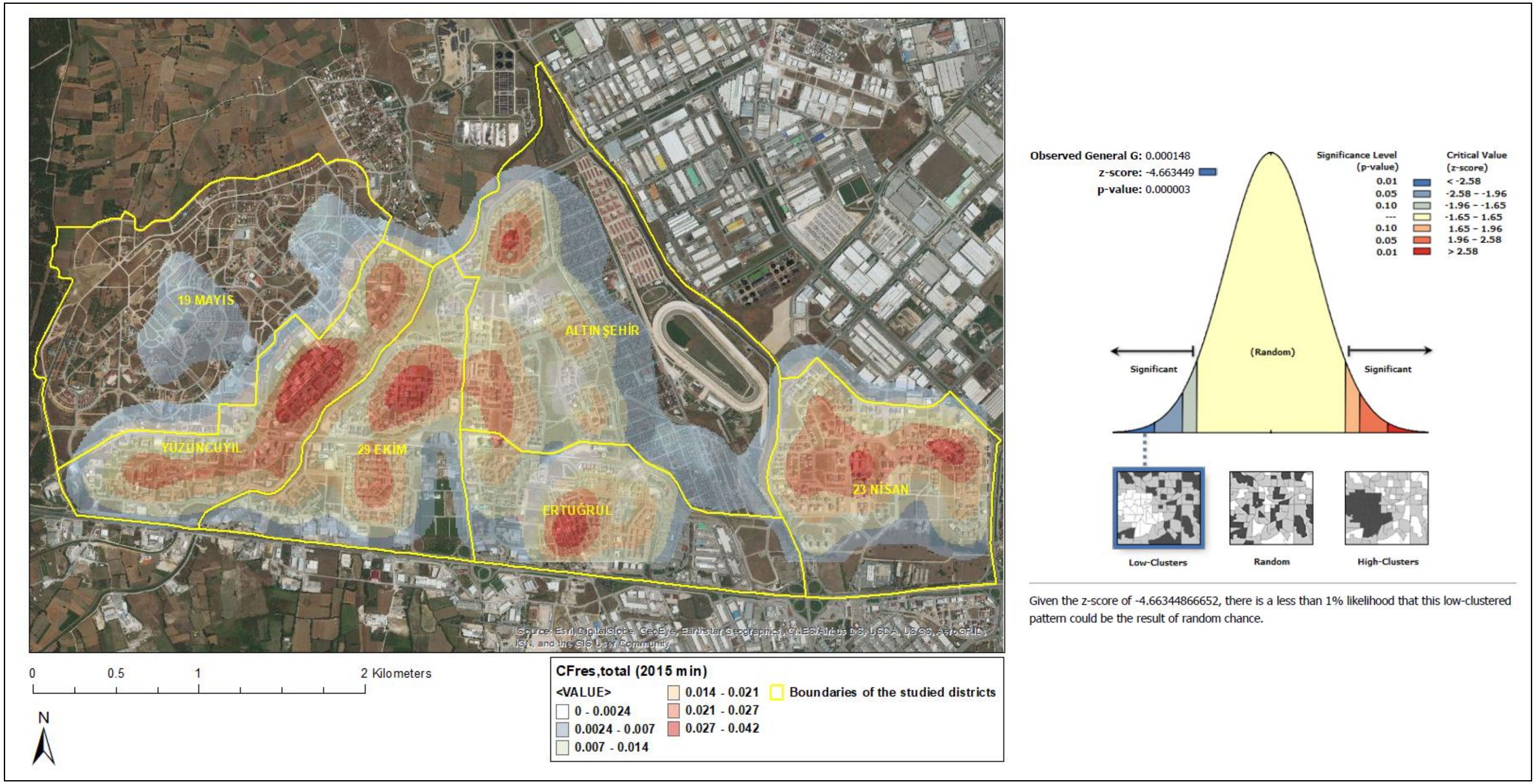


Figure 4-35. Kernel Density Map for CFres,total (2015 min)

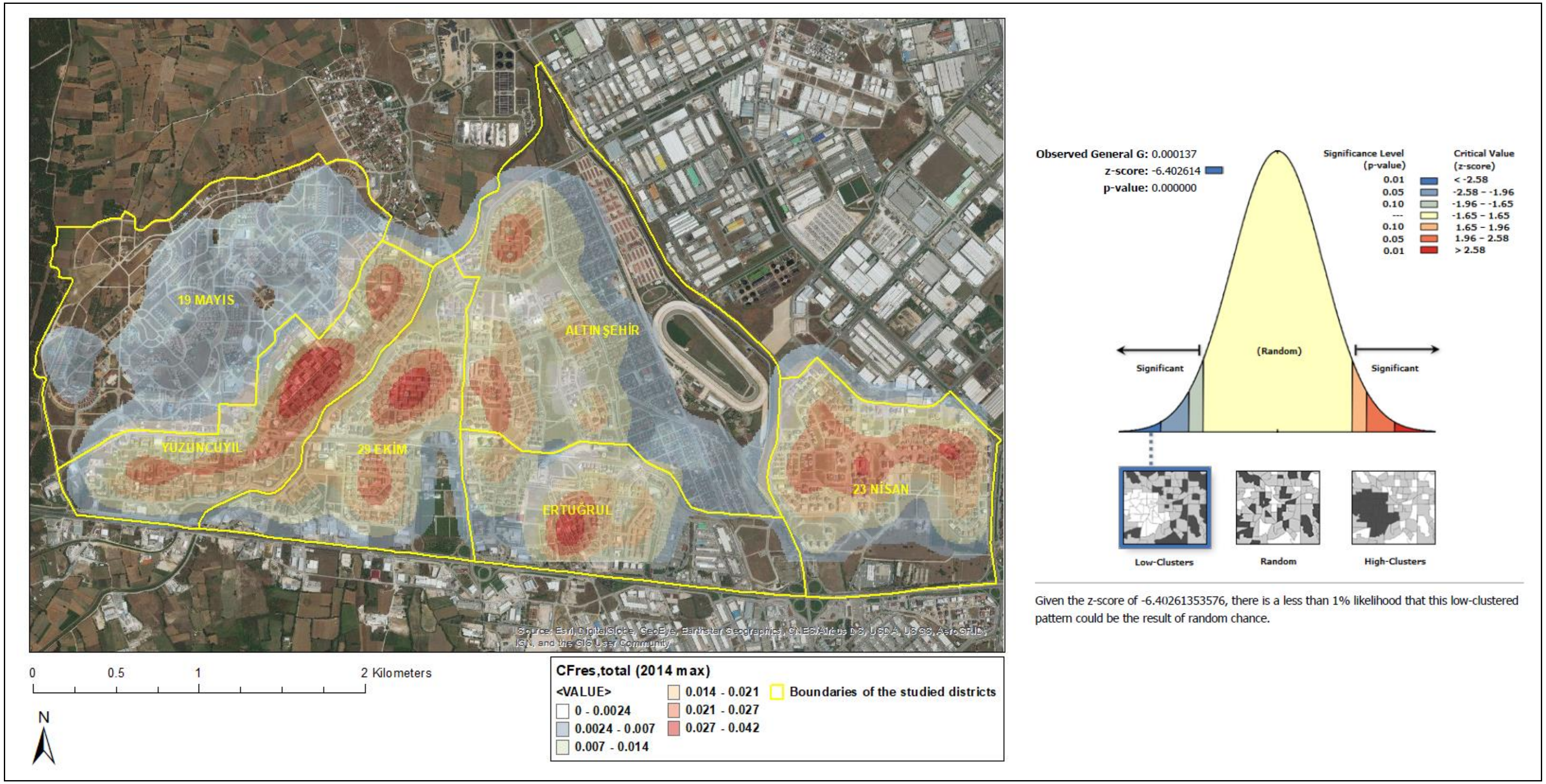


Figure 4-36. Kernel Density Map for CFres,total (2014 max)

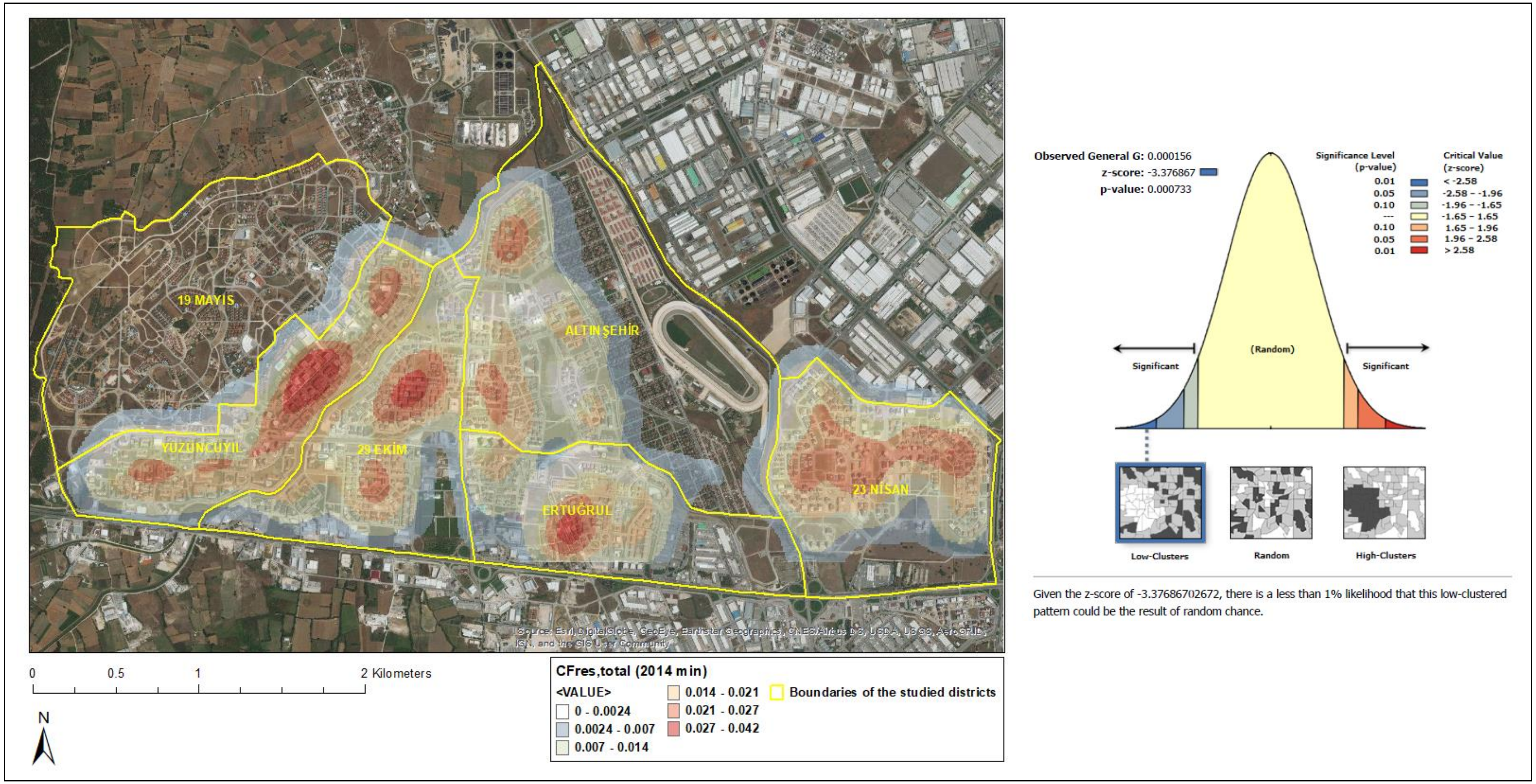


Figure 4-37. Kernel Density Map for CFres,total (2014 min)

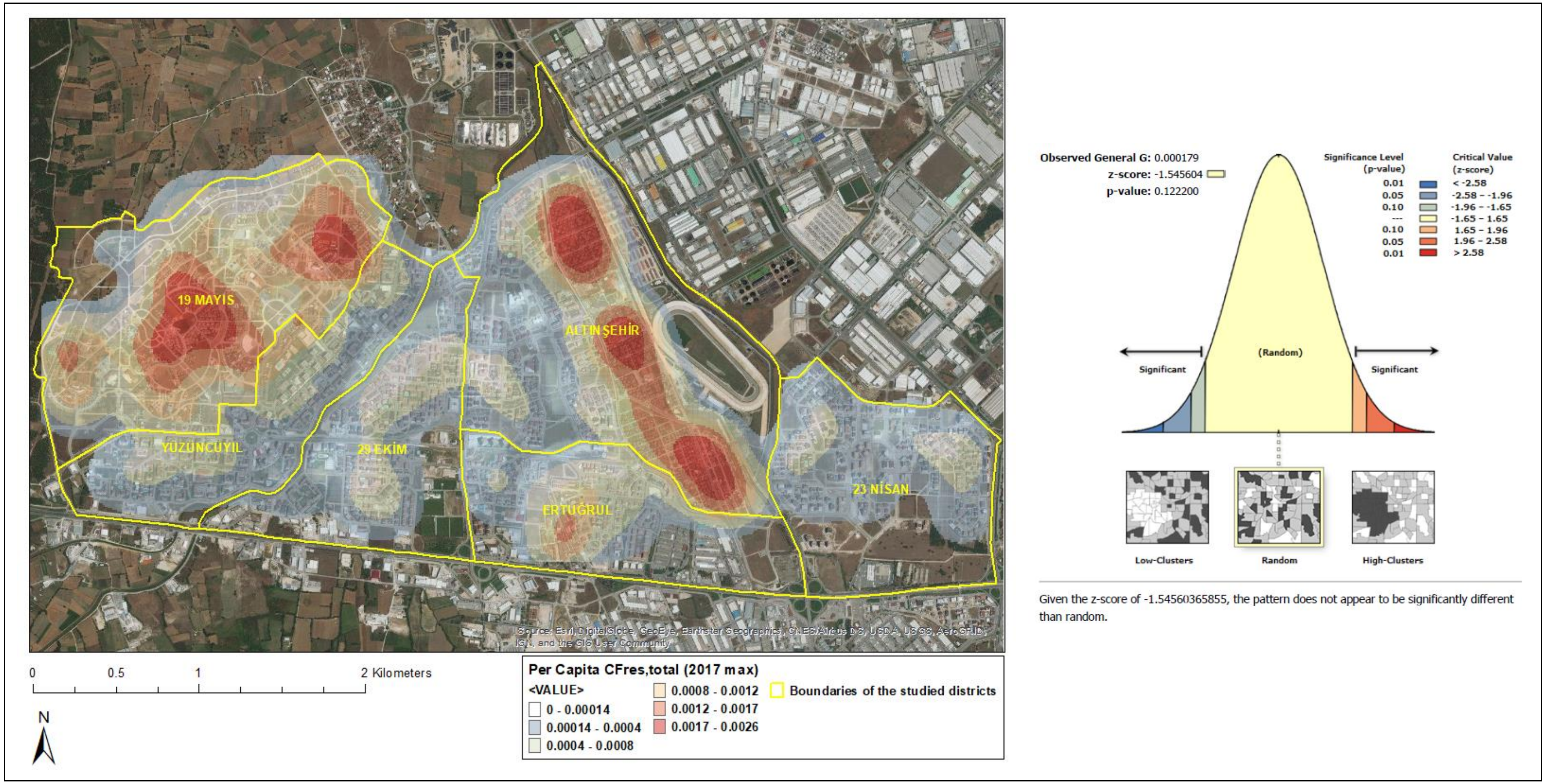


Figure 4-38. Kernel Density Map for Per Capita CFres,total (2017 max)

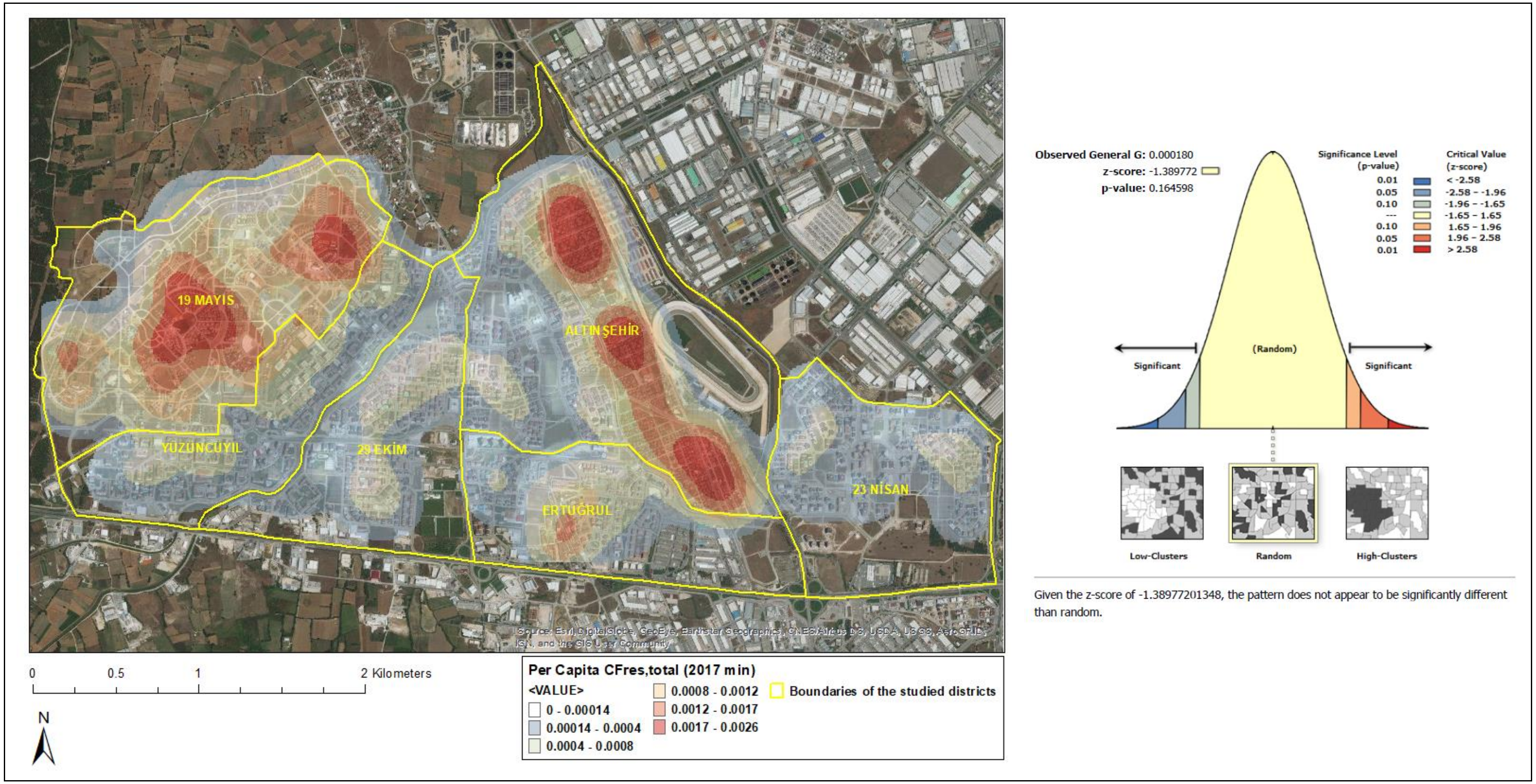


Figure 4-39. Kernel Density Map for Per Capita CFres,total (2017 min)

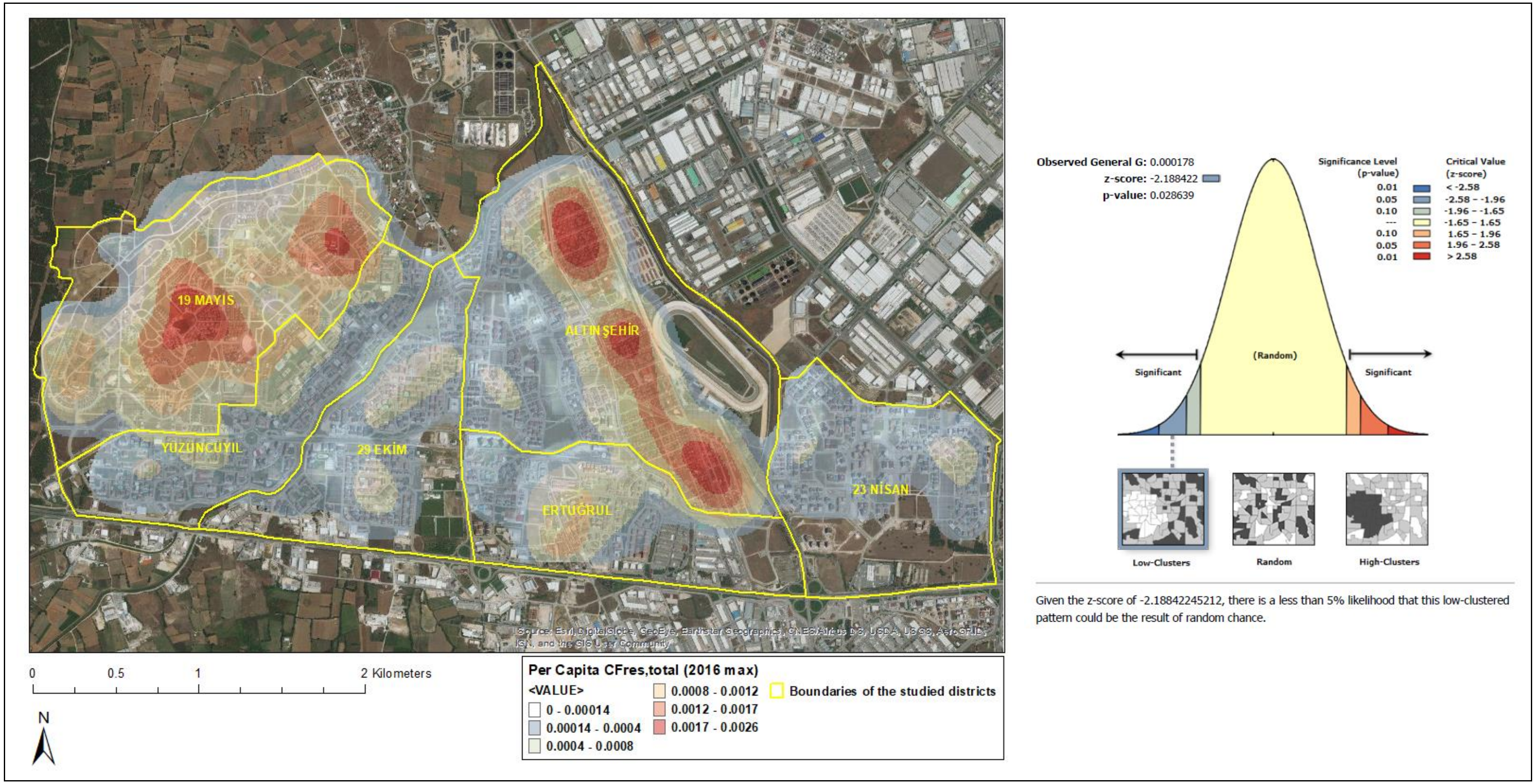


Figure 4-40. Kernel Density Map for Per Capita CFres,total (2016 max)

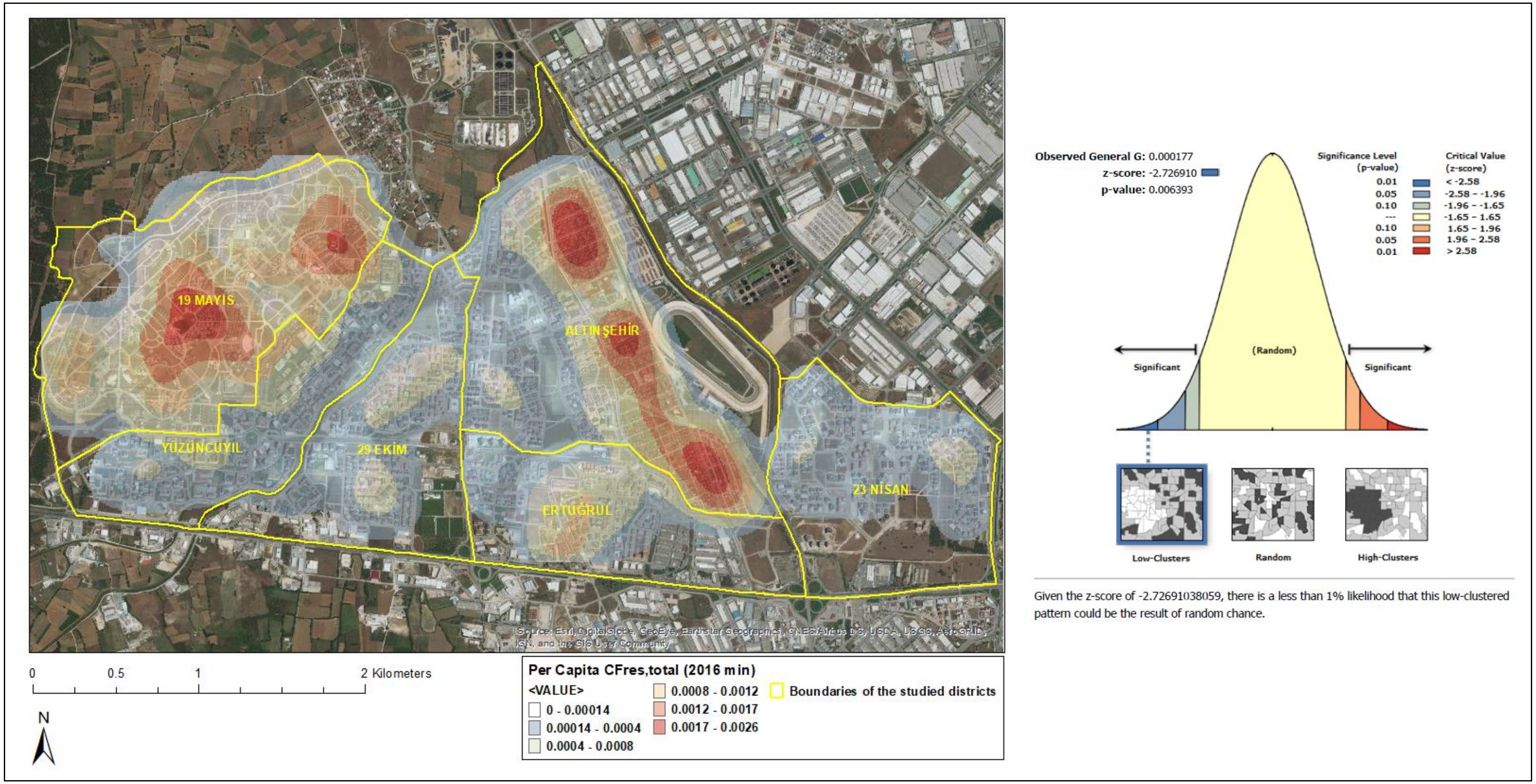


Figure 4-41. Kernel Density Map for Per Capita CFres,total (2016 min)

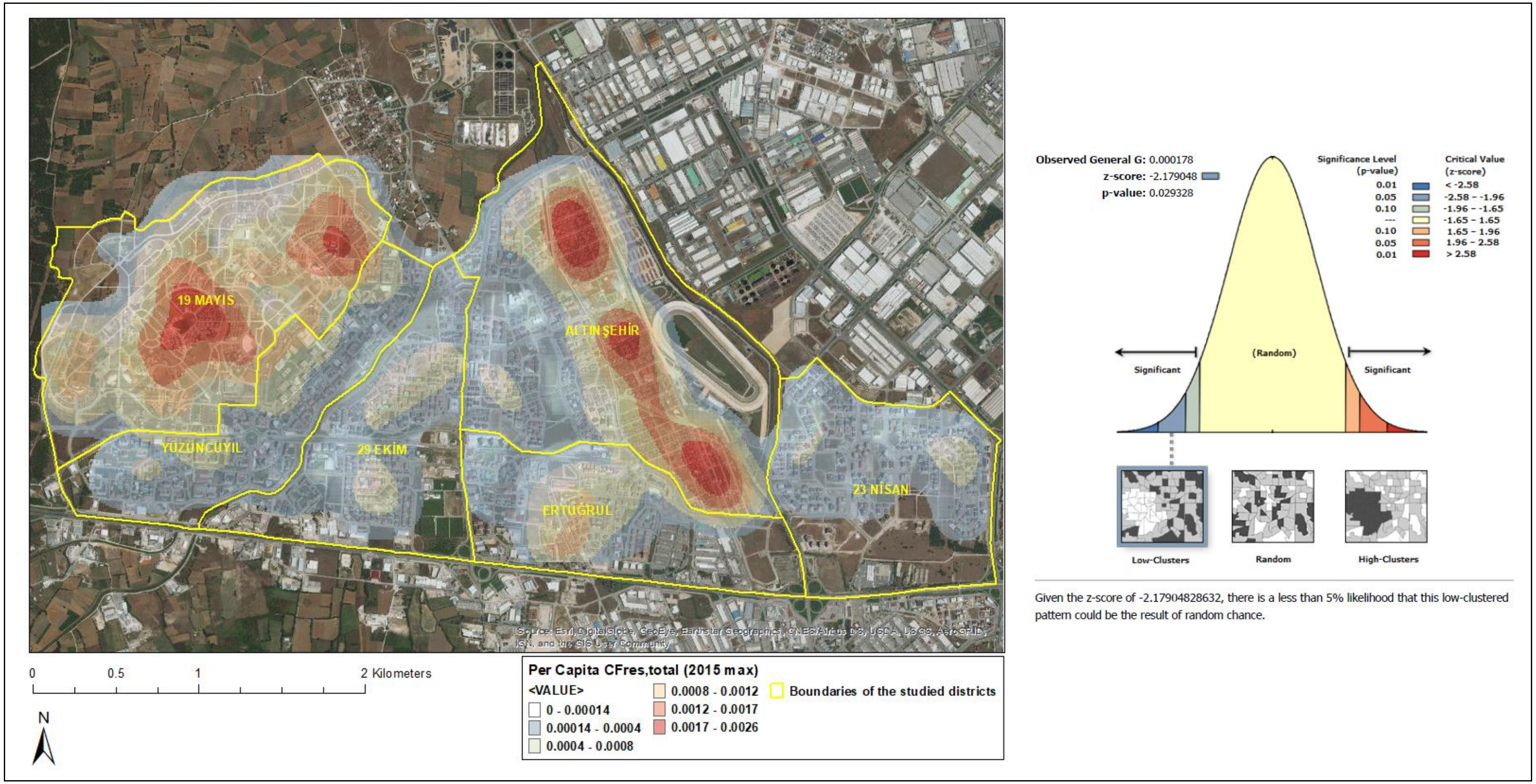


Figure 4-42. Kernel Density Map for Per Capita CFres,total (2015 max)

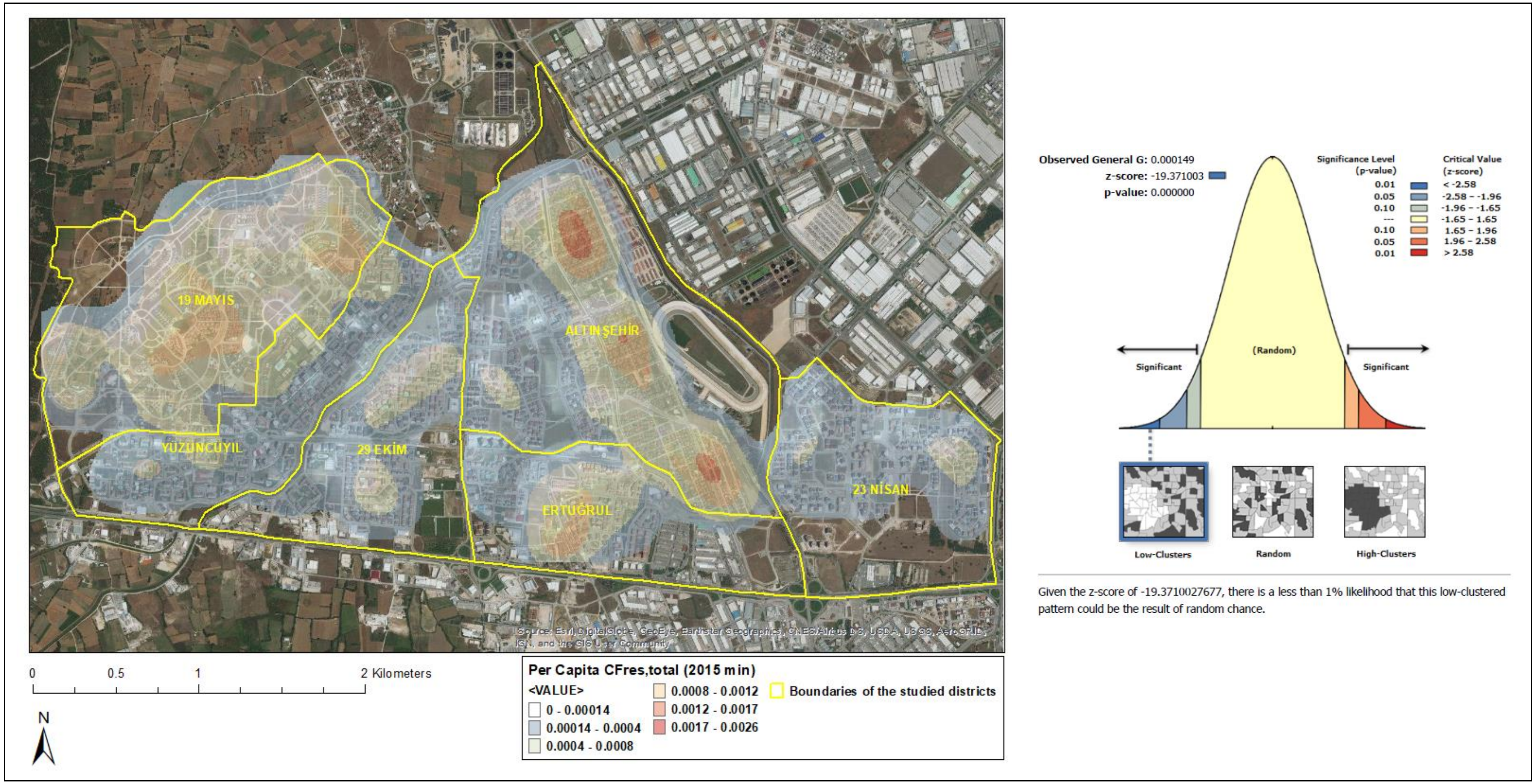


Figure 4-43. Kernel Density Map for Per Capita CFres,total (2015 min)

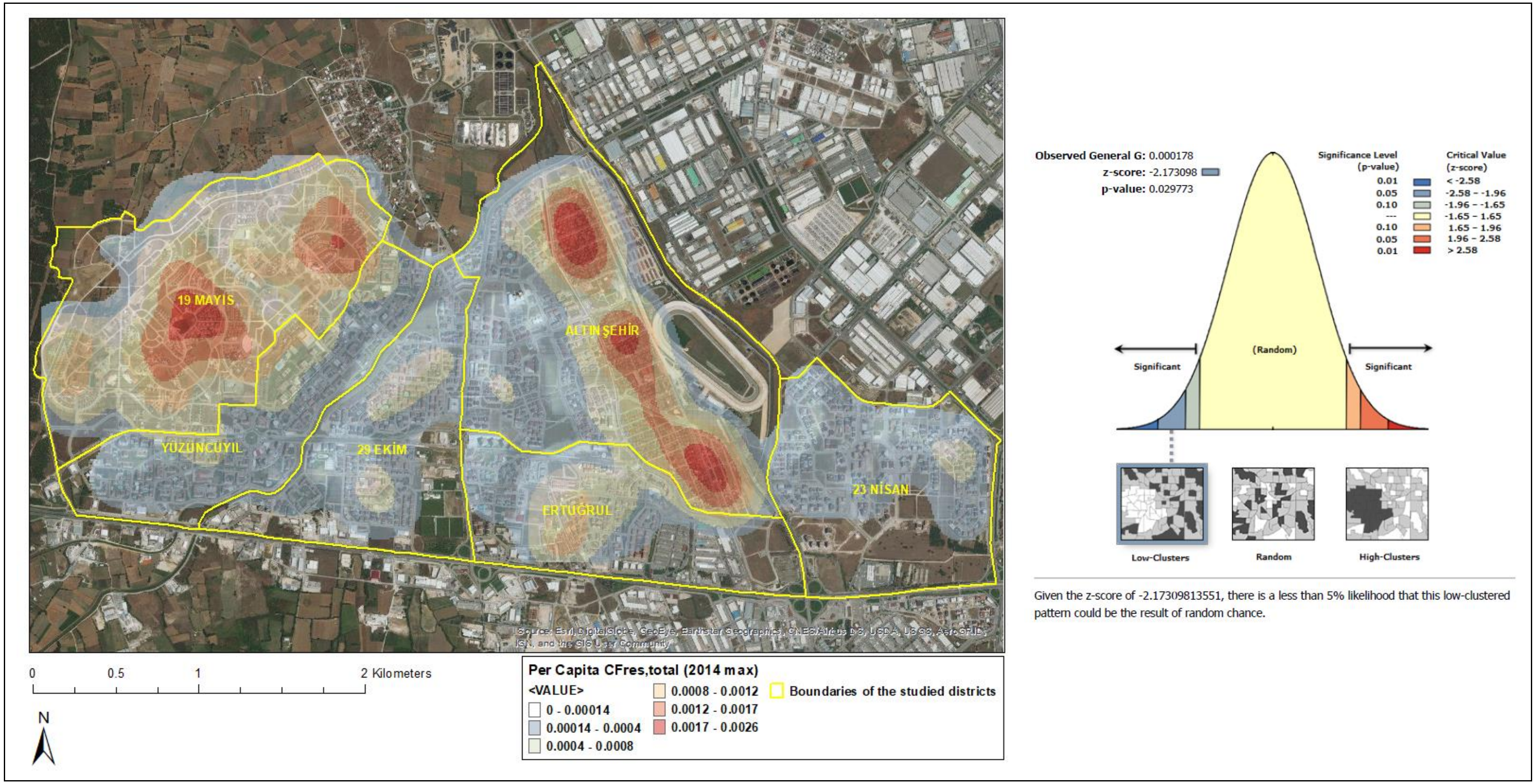


Figure 4-44. Kernel Density Map for Per Capita CFres,total (2014 max)

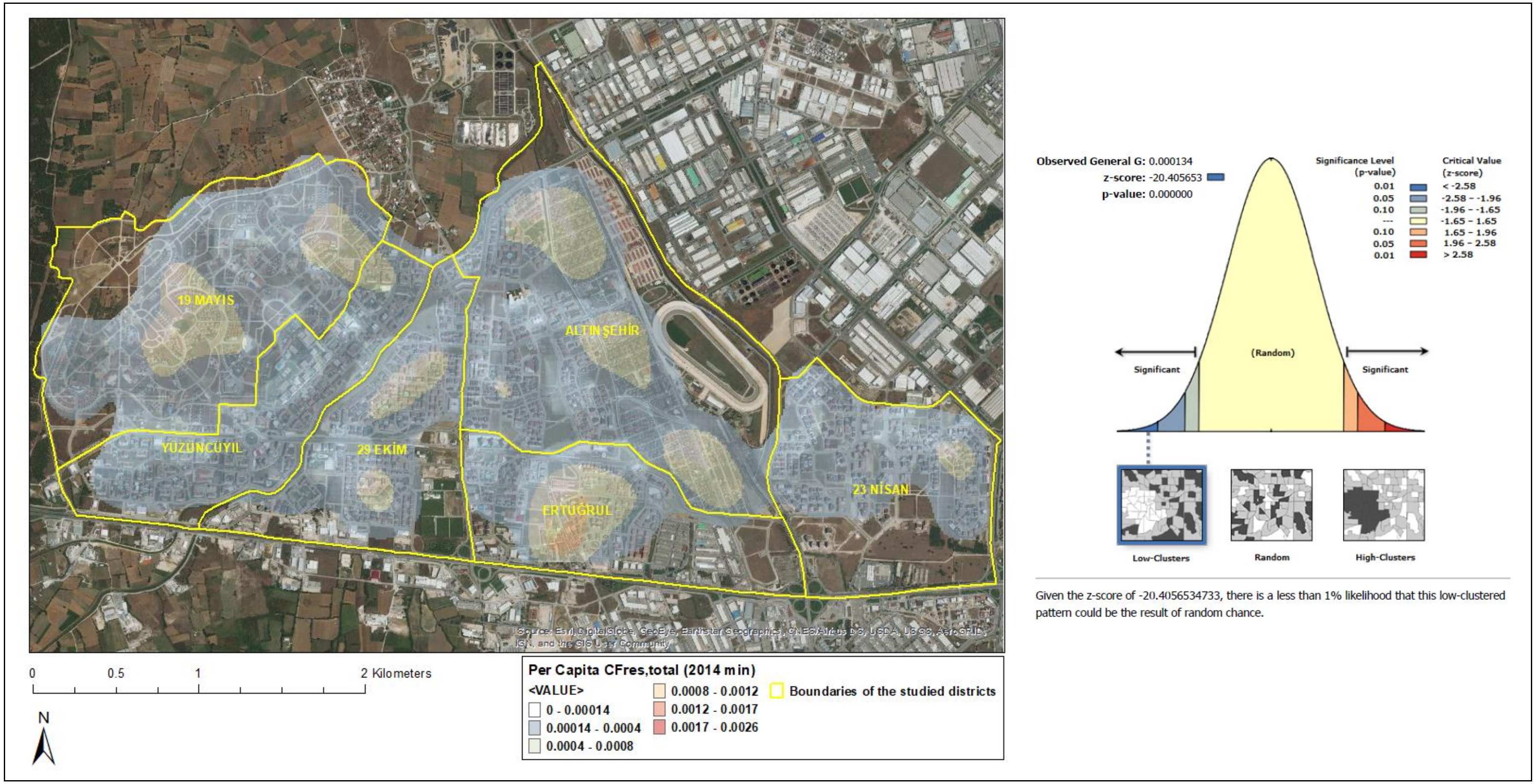
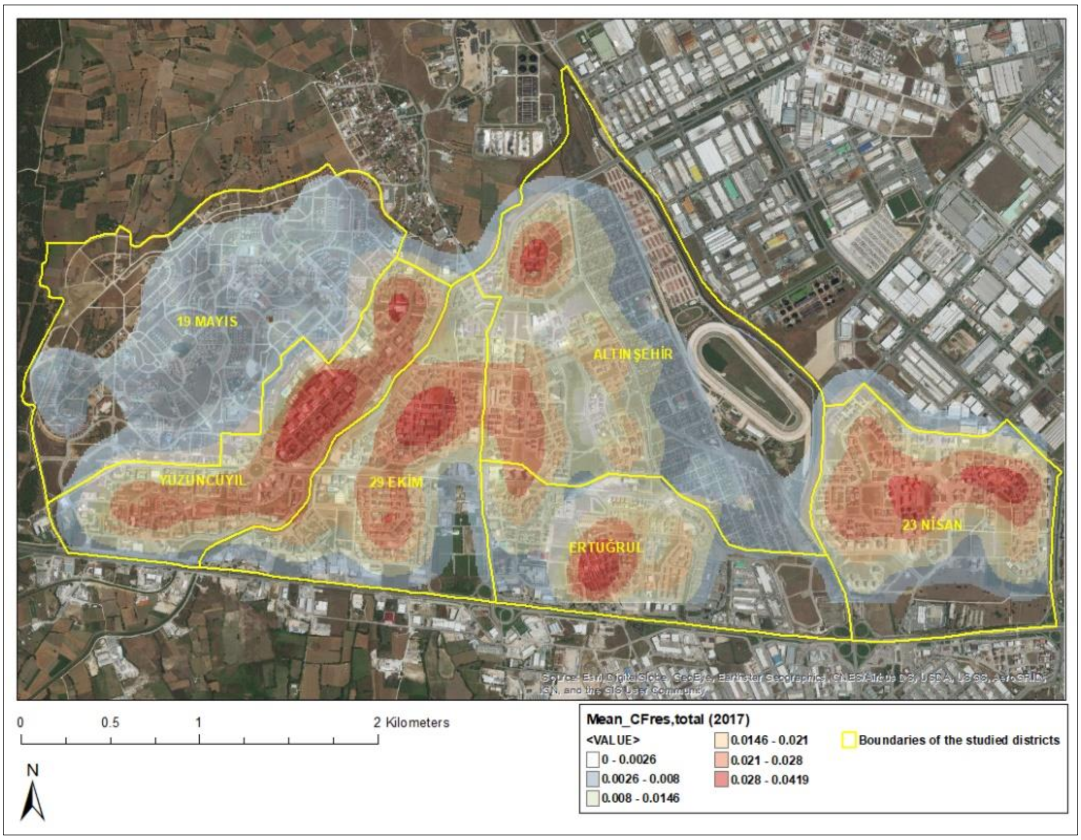


Figure 4-45. Kernel Density Map for Per Capita CFres,total (2014 min)



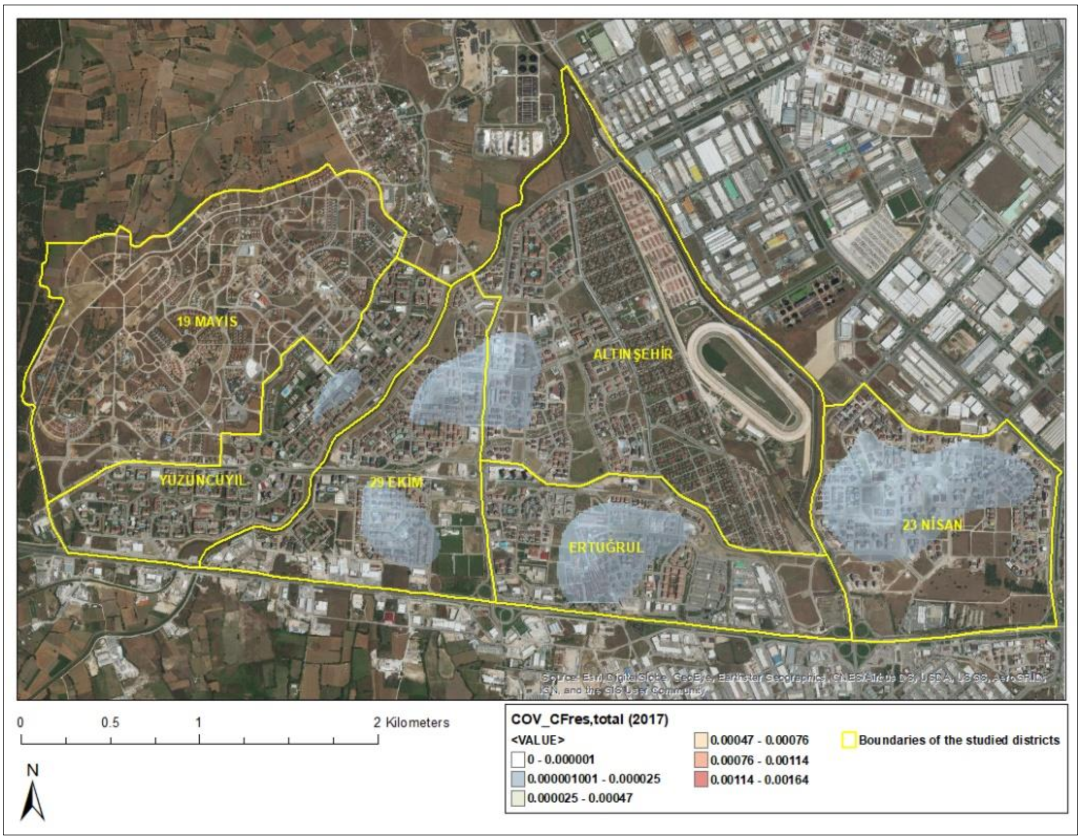


Figure 4-46. Kernel Density Maps for Mean (top) and COV (bottom) of CFres,total (2017)

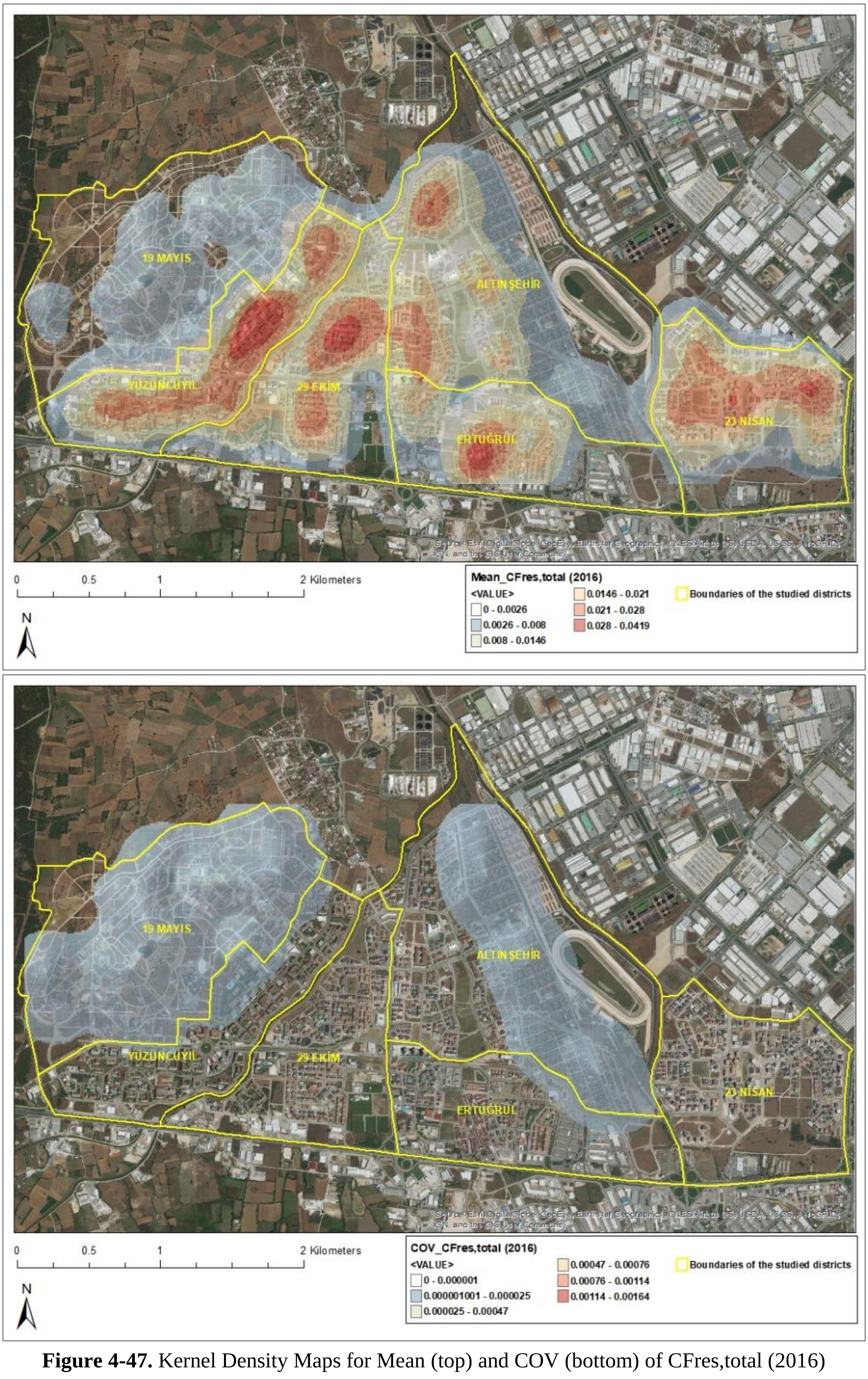


Figure 4-47. Kernel Density Maps for Mean (top) and COV (bottom) of CFres,total (2016)

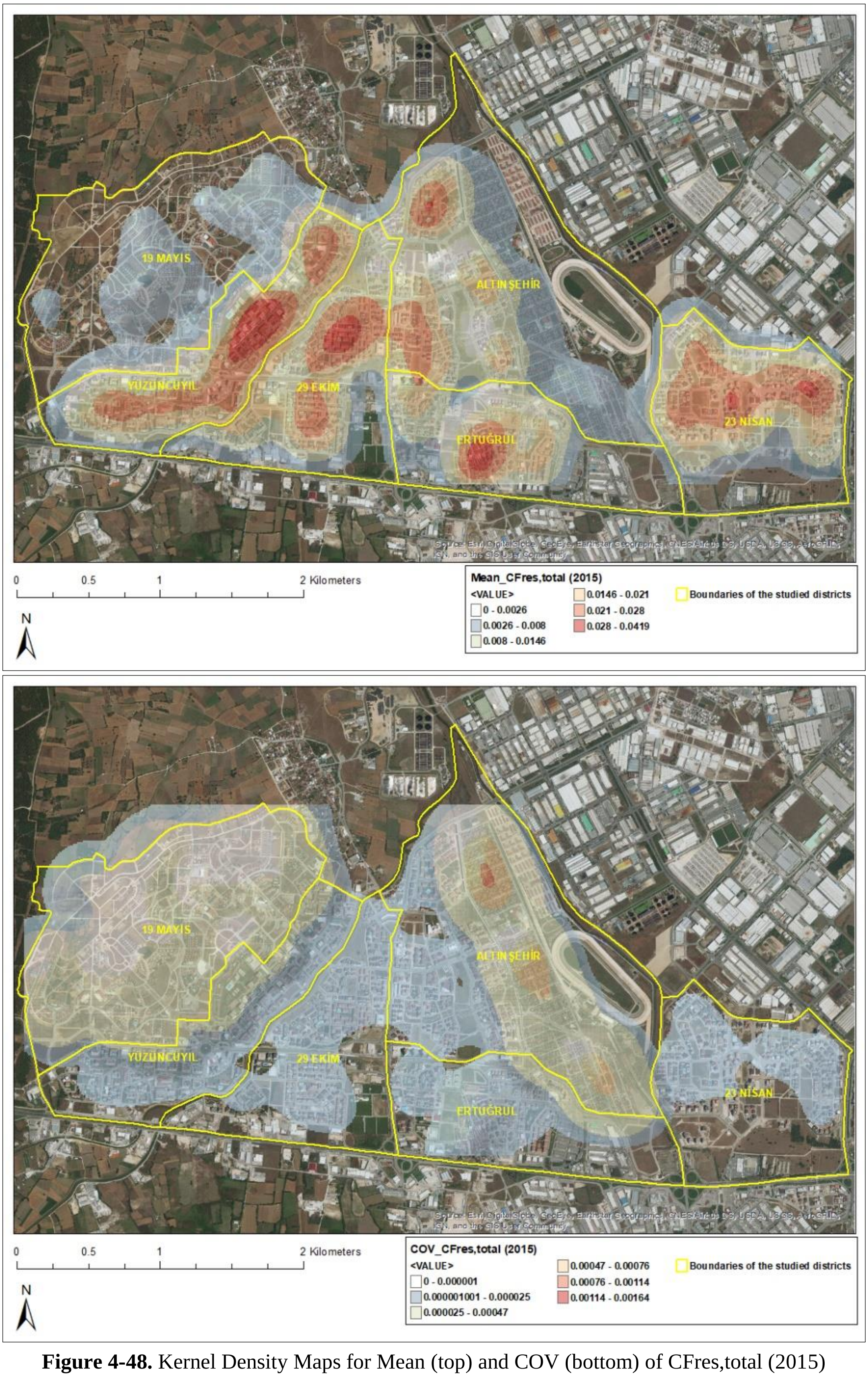
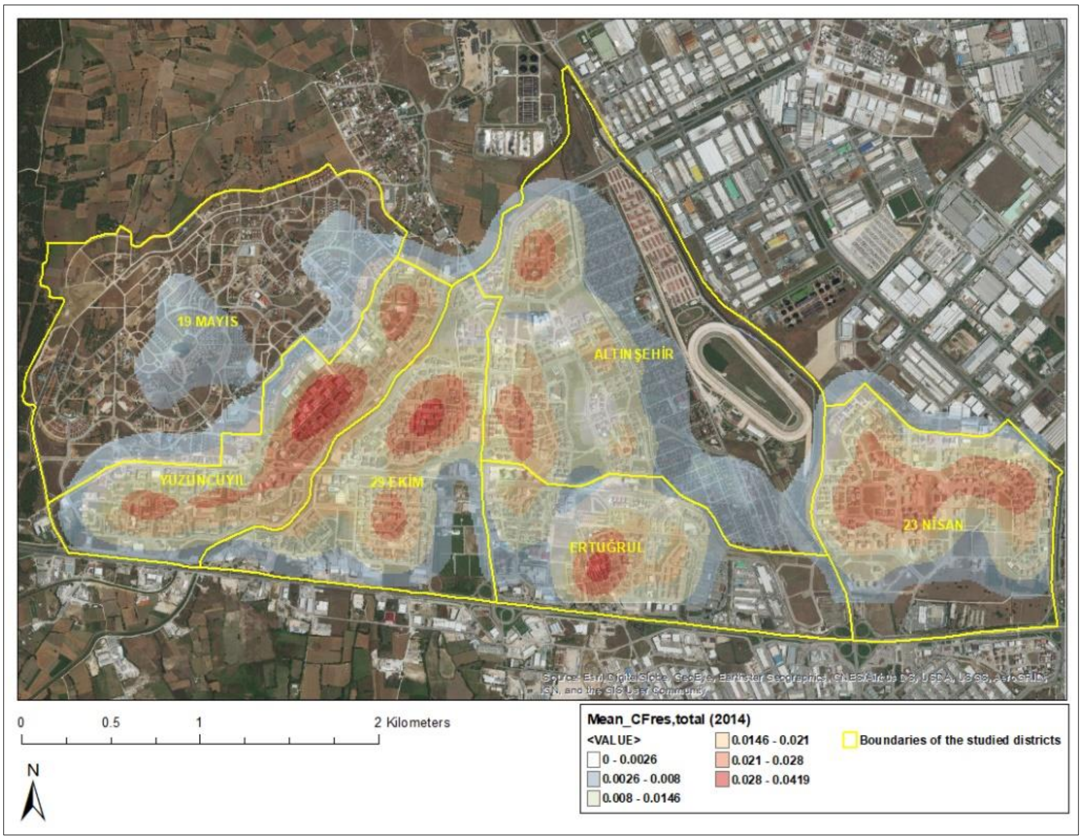


Figure 4-48. Kernel Density Maps for Mean (top) and COV (bottom) of CFres,total (2015)



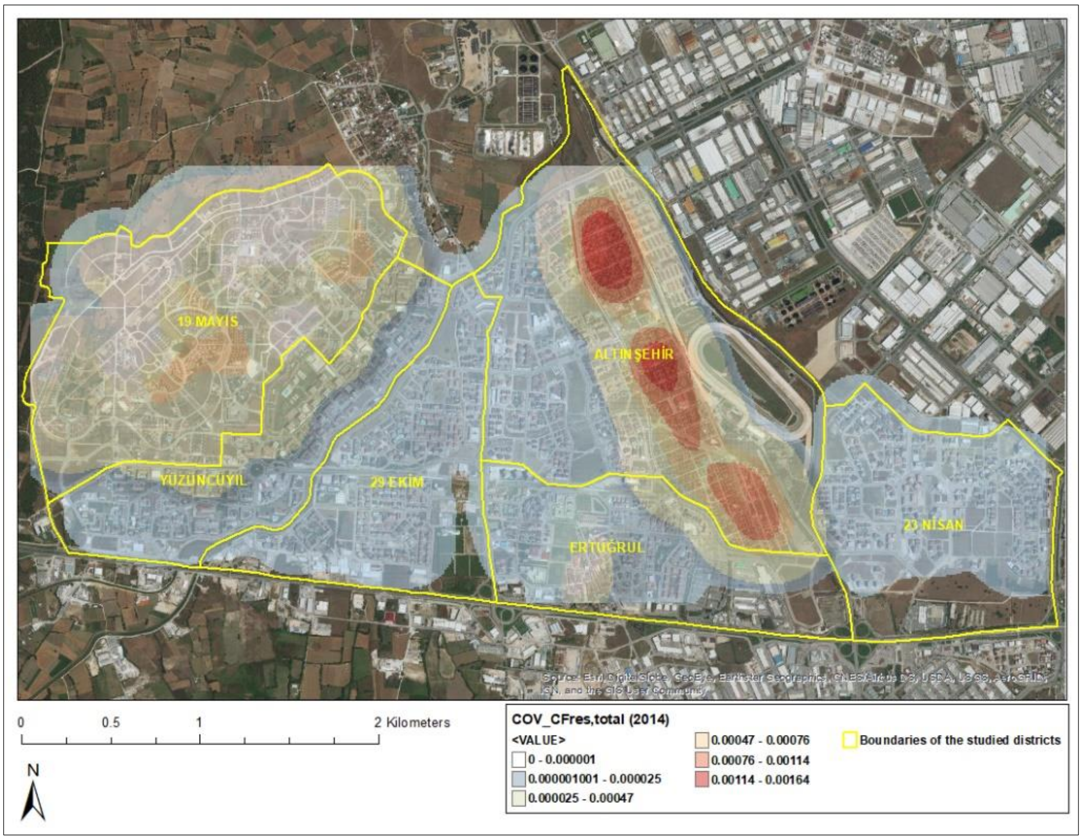


Figure 4-49. Kernel Density Maps for Mean CFres,total and COV of CFres,total (2014)

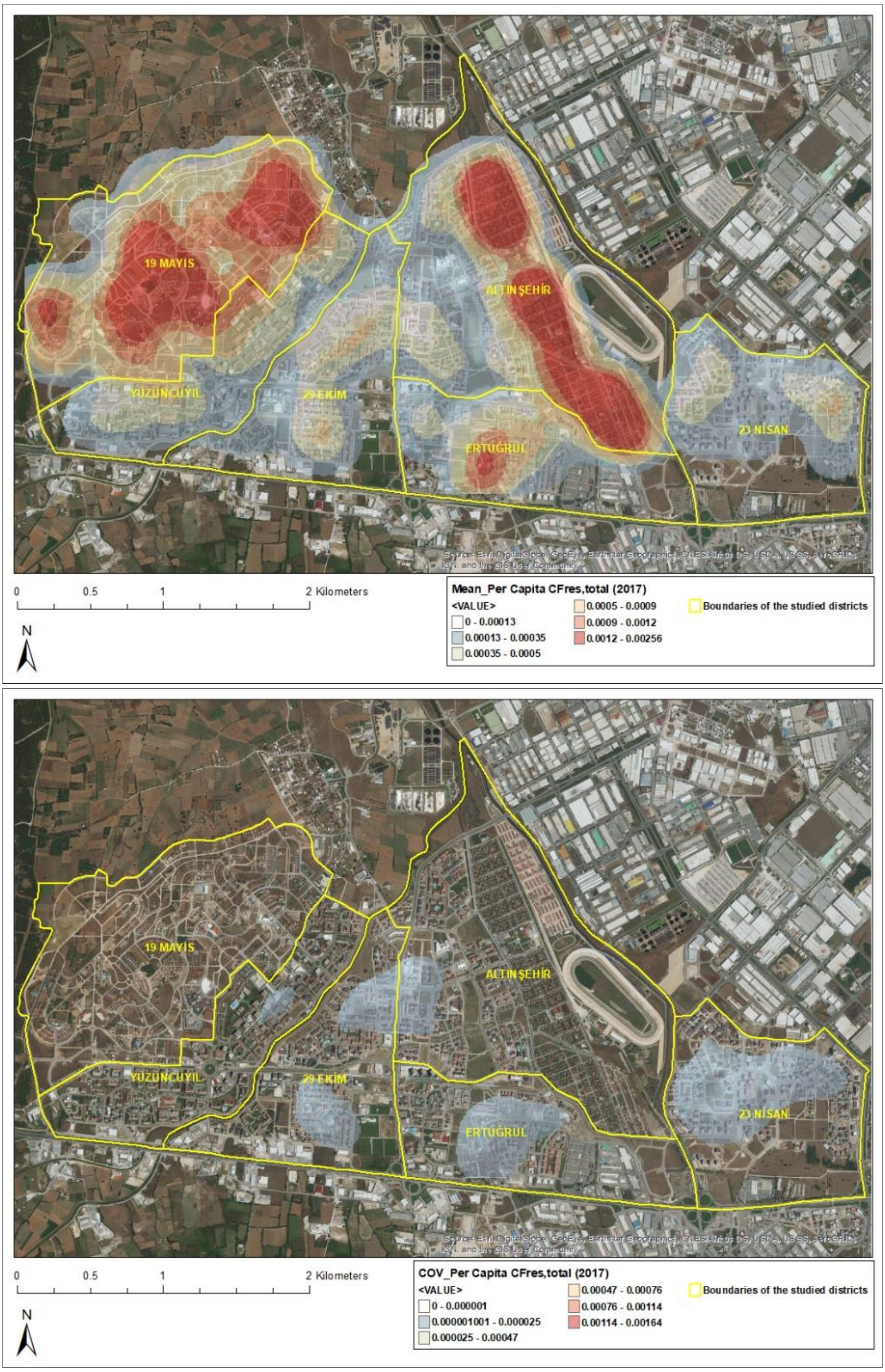


Figure 4-50. Kernel Density Maps for Mean (top) and COV (bottom) of Per Capita CFres,total (2017)

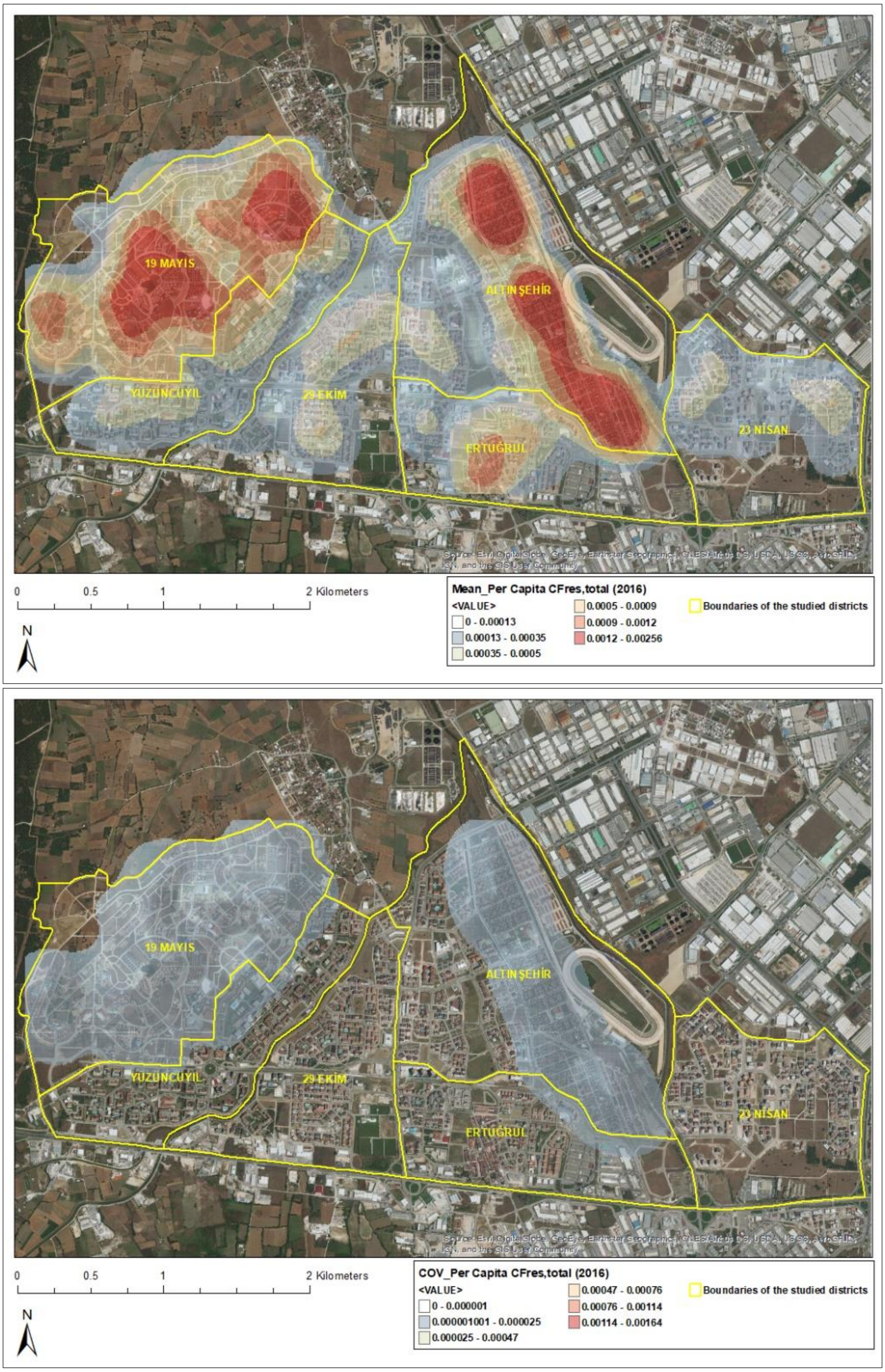


Figure 4-51. Kernel Density Maps for Mean (top) and COV (bottom) of Per Capita CFres,total (2016)

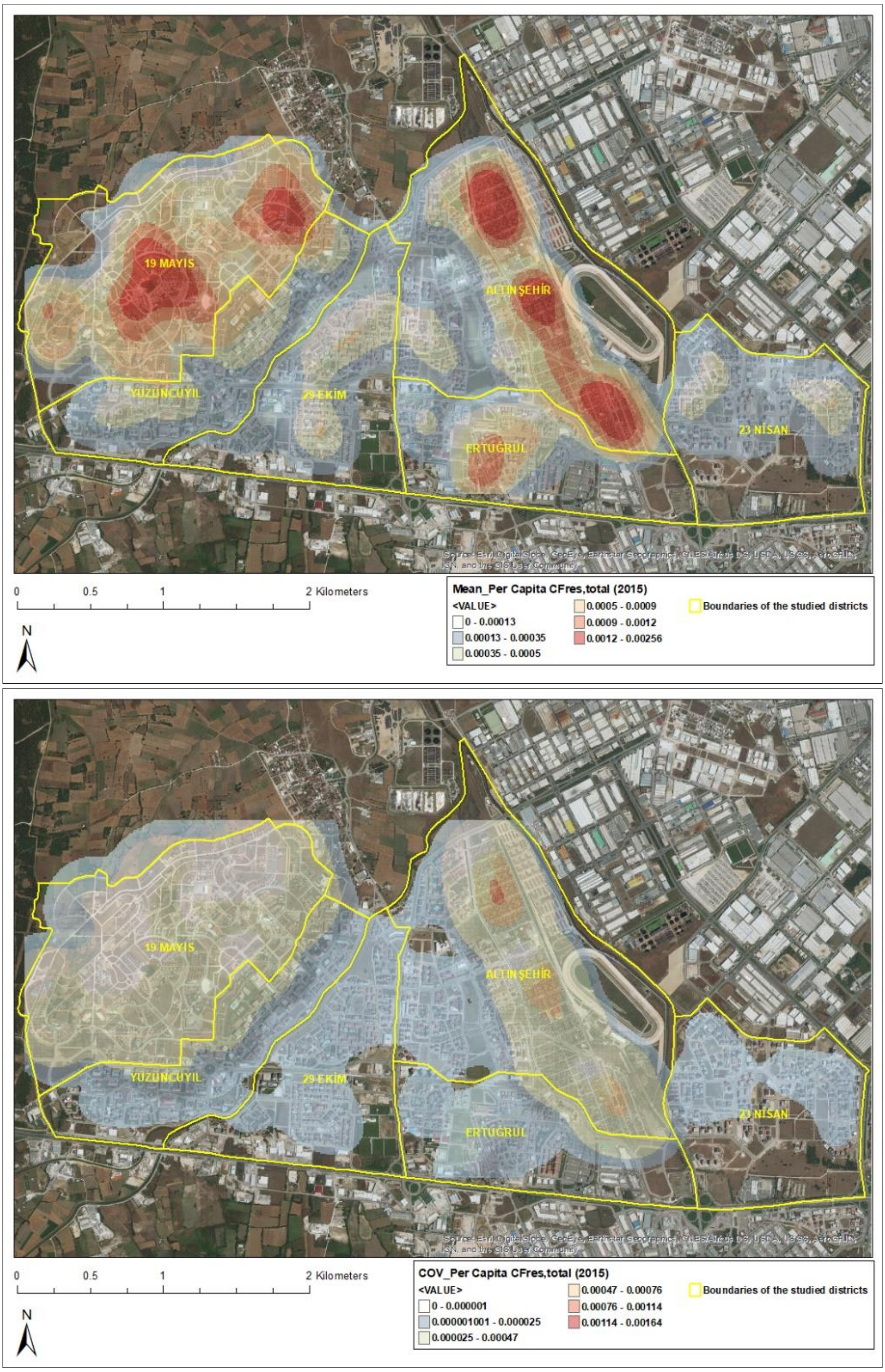
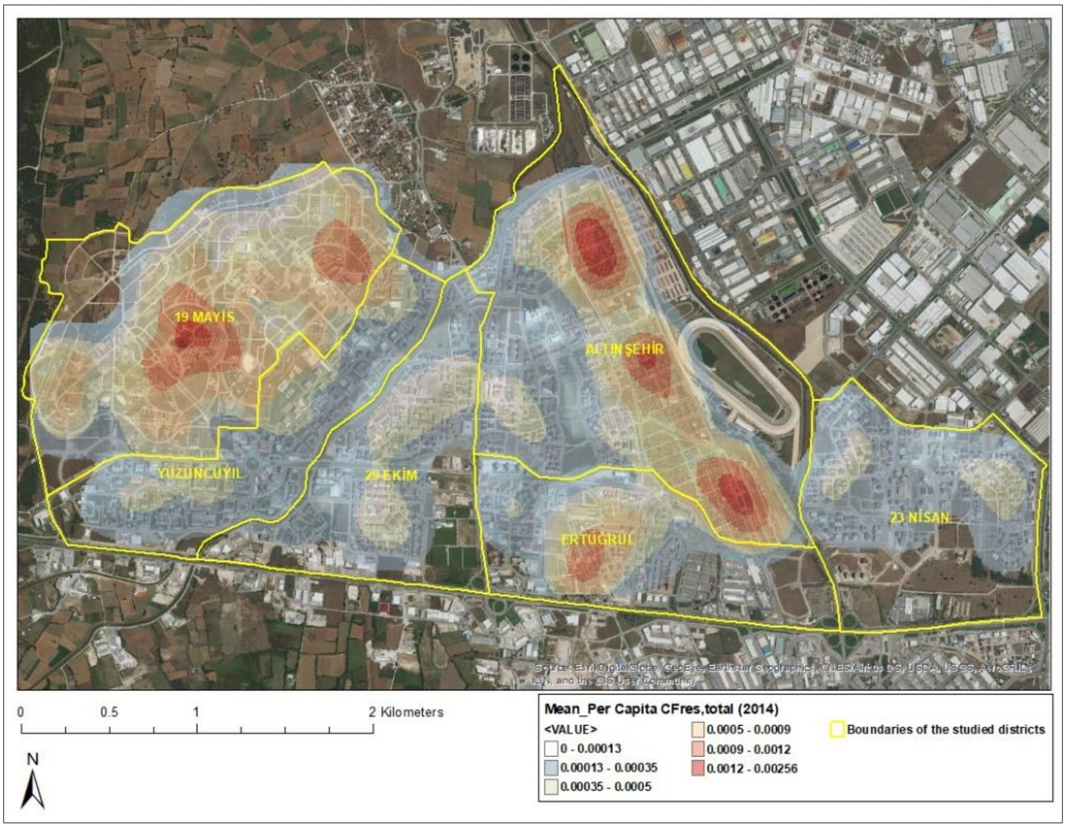


Figure 4-52. Kernel Density Maps for Mean (top) and COV (bottom) of Per Capita CFres,total (2015)



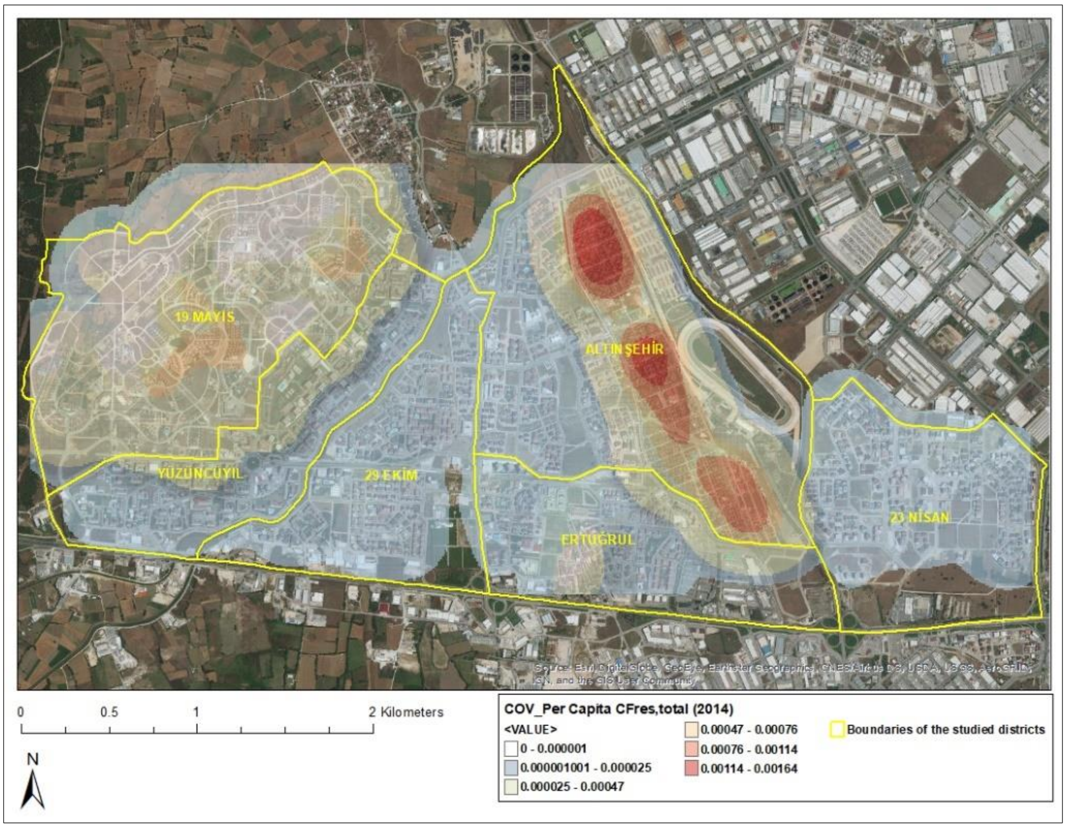


Figure 4-53. Kernel Density Maps for Mean (top) and COV (bottom) of Per Capita CFres,total (2014)

3.5 Discussions of Spatial Analyses

In this section, comments, discussions and policy implications driven from the results of spatial analyses, which were presented in the previous section, are provided.

First of all, in parallel to the CF calculation results discussed in Section 3.3, the difference between “minimum” and “maximum” scenarios is only noticeable in 2014 and 2015 in most of the analysis results. Only minor differences are observed between the minimum and maximum scenarios of 2016 and 2017. This may again be tied to the possibility that 19 Mayıs Neighborhood is a relatively new neighborhood and the single houses here may be built/sold after 2015.

To interpret the differences between “minimum” and “maximum” scenarios more precisely, a much larger number of sample buildings have to be used. As per the limitation of this study, incorporating a large set of sample buildings could not be possible. Instead, density maps of mean values (i.e. average of minimum & maximum scenarios) and coefficient of variation (COV) are provided for each year to better demonstrate the scale of difference between minimum and maximum scenarios through years and detect where the average values and COVs concentrate. The results will be discussed in the general framework of all eight scenarios except the cases where the difference between minimum and maximum scenarios are distinct. The comments and discussions of the statistical and spatial analyses can be listed as follows:

- According to the histogram graphs in Table 4-4, the value range (i.e. the bin) for $CF_{res,total}$ where the largest number of data points (out of 3807 customer points in total) are collected is “**≤ 6 tCO_2**” with more than 1200 customer points in 2017. It is closely followed by **“6 - 16 tCO_2”** bin with more than 1000 customer points. In 2016, the bin with largest number of data point is “**≤ 5.1 tCO_2**” with around 1200 customer points which is closely followed by **“5.1 - 14.5 tCO_2”** bin with around 1100 customer points. In 2015, the largest number of data points fall into the **“≤13.2 tCO_2”** range, and in 2014, the largest number of data points fall into the **"≤10.4 tCO_2"** range. Thus, it can be concluded that the emission values of the bins, where the majority of data points fall into, show an increasing trend from 2014 to 2017.

- The histogram graphs in Table 4-5 indicate that the bin for Per Capita $CF_{res,total}$ where the largest number of data points are collected is "**0.98 - 1.14 tCO_2/person"** with more than 1000 customer points in 2017. In 2016, the bin with largest number of data point is "**0.92 - 1.06 tCO_2/person"** with around 1100 customer points. In 2015, the largest number of data points fell into the **"0.88 - 1.03 tCO_2/person"** range in the maximum scenario, and into the **"≤0.62 tCO_2/person"** range in the minimum scenario. In 2014, the largest number of data points fell into the **"0.91 - 1.05 tCO_2/person"** range in the maximum scenario, and into the **"≤0.35 tCO_2/person"** range in the minimum scenario. An increasing trend is again observable from 2014 to 2017 in the emission values of the bins where the majority of data points fall into.
- By looking at the classification maps provided for $CF_{res,total}$ from Scenario 1 to 8 in Figure 4-6 to Figure 4-13, it can be concluded that there is almost no change in the distribution of classes that customer points fall into. In other words, the same building types generally belong to the same emission class such as *"very low"* or *"moderate";* and thus, the colors of the dots do not change much between different scenarios, although minor switches can be observed. However, as can be seen from the legends, the emission intervals representing each class change for every scenario in line with the calculated CF values, which is an expected outcome. For example, the *"very high"* emission class represented with red dots refers to "**309.0 to 516.91 tCO_2"** range in 2017 maximum (see Figure 4-6) while it refers to "**259.0 to 452.75 tCO_2"** range in 2014 minimum (see Figure 4-13). When the results of these maps are matched with building patterns in the area, it can be clearly seen that the dark green dots that refer to *"very low"* emission class (compared to the overall CF results) represent the single houses located in 19 Mayıs and

Altınşehir Neighborhoods. This is reasonable since single houses have a lower $CF_{res,total}$ compared to multi-storey (apartment-type) buildings due to their smaller floor area. In contrast, the higher the number of floors and the wider the floor area are, the higher the $CF_{res,total}$ of a particular building becomes. Accordingly, it can be seen that the blocks in "Saygınkent Complex", in which the DH-type sample building is located (see Figure 3-21), are represented with red dots that represent *"very high"* emissions. This is also reasonable since Saygınkent Complex composes of seven identical 18-storey residential blocks with floor areas above 1220 m^2. Likewise, the emission classes in between are represented with apartment-type buildings with different number of floors and various floor areas. It can be seen that the yellow, orange and red dots mostly accumulate over 23 Nisan, Yüzüncüyıl and 29 Ekim, due to their relatively higher total residential area, which can be double-checked from the floor areas and number of floors provided in Table 3-6.

- The classification maps provided for Per Capita $CF_{res,total}$ from Scenario 1 to 8 in Figure 4-14 to Figure 4-21 provide a completely different distribution of emission classes than the previous maps for $CF_{res,total}$. It can clearly be seen that as of 2015, "*moderate", "high"* and *"very high"* per capita residential emission classes are mostly accumulated in 19 Mayıs Neighborhood, which contains relatively newer and luxurious single houses with larger floor area than the single houses located in Altınşehir Neighborhood. It can also be seen that a few single houses located near the Ertuğrul boundary of Altınşehir Neighborhood are also represented with yellow, orange and red dots, but not as much as 19 Mayıs single houses. This can again be tied to the possibility that 19 Mayıs single houses are built/sold after 2015. As a supporting fact, in the 2014 and 2015 minimum scenarios (see Figure 4-19 and Figure 4-21), where most of the 19 Mayıs single houses were assumed to be vacant, the distribution of yellow, orange and red dots shifts to apartment-type buildings.

- By again looking at the classification maps provided for Per Capita $CF_{res,total}$ in Figure 4-14 to Figure 4-21, it can be seen that the Per Capita $CF_{res,total}$ values represented with red dots are mostly found in 19 Mayıs single houses; and they equal approximately 4-5 times the average Per Capita $CF_{res,total}$ values calculated in this study and also in the GHG inventories prepared for Bursa.

- It can be seen that the hot spot analysis maps presented in Figure 4-22 to Figure 4-29 reveal consistent results with the previous classification maps. These maps show where statistically significant hot spots (high values) and cold spots (low values) cluster in the area of study; and hot and cold spots with ≥ 95% confidence level are taken into consideration for this study. As can be seen from Figure 4-22 to Figure 4-25, high $CF_{res,total}$ values cluster in apartment-type buildings located in Yüzüncüyıl, 29 Ekim, Altınşehir and 23 Nisan Neighborhoods while the cold spots cluster in single houses located in 19 Mayıs and Altınşehir Neighborhoods. There is not a noticeable difference between "minimum" and "maximum" scenarios of 2016 and 2017, as in the case of previous analyses. The difference is only noticeable in 2014 and 2015. As a supporting fact, the numbers of hot spots and cold spots for CFres,total values with ≥ 95% confidence level are presented in Table 4-6 for each scenario.

Table 4-6. Numbers of Hot Spots and Cold Spots for CFres,total by Scenarios

Scenarios / $CF_{res,total}$ values	**Number of Hot Spots (≥ 95% confidence)**	**Number of Cold Spots (≥ 95% confidence)**
2017 Maximum	997	2107
2017 Minimum	997	2109
2016 Maximum	1003	2109
2016 Minimum	1006	2111
2015 Maximum	997	2109
2015 Minimum	1013	2141
2014 Maximum	995	2106
2014 Minimum	1019	2168

As can be seen, a difference of only a few spots exists between the minimum and maximum scenarios in 2017 and 2016, which is hardly visible on the maps. On the other hand, an average difference of 1.5% is observed in 2015 and an average difference of 2.6% is observed in 2014 between minimum and maximum scenarios.

- The maps for Per Capita $CF_{res,total}$ in Figure 4-26 to Figure 4-29 indicate that hot spots mostly cluster in 19 Mayıs Single houses; and a few single houses located near the Ertuğrul boundary of Altınşehir Neighborhood, in line with the previous classification maps. Likewise, in 2014 and 2015 minimum scenarios (see Figure 4-28 and Figure 4-29), where most of the 19 Mayıs single houses were assumed to be vacant, the clustering of hot spots shifts to apartment-type buildings from 19 Mayıs single houses. Similar to the $CF_{res,total}$ maps, there is not a noticeable difference between "minimum" and "maximum" scenarios of 2016 and 2017, as in the case of previous analyses. The difference is only noticeable in 2014 and 2015. As a supporting fact, the numbers of hot spots and cold spots for Per Capita $CF_{res,total}$ values with ≥ 95% confidence level are presented in Table 4-7 for each scenario.

Table 4-7. Numbers of Hot Spots and Cold Spots for Per Capita CFres,total by Scenarios

Scenarios / Per Capita $CF_{res,total}$ values	Number of Hot Spots (≥ 95% confidence)	Number of Cold Spots (≥ 95% confidence)
2017 Maximum	1024	1685
2017 Minimum	1024	1696
2016 Maximum	1019	1636
2016 Minimum	1016	1607
2015 Maximum	1021	1641
2015 Minimum	958	1190
2014 Maximum	1021	1652
2014 Minimum	1391	1443

As can be seen, a difference of only a small number of spots exists between the minimum and maximum scenarios in 2017 and 2016, which is hardly visible on the maps. On the other hand, an average difference of 16.8% is observed in 2015 and an average difference of 19.6% is observed in 2014 between minimum and maximum scenarios.

- The Kernel Density maps provided in Figure 4-30 to Figure 4-45 represent the area-based CF densities; in other words, emission magnitudes per unit area. The results of Kernel Density maps are consistent with previous classification maps and hot spot analysis maps in general, except for the Per Capita $CF_{res,total}$ density over the single houses in Altınşehir Neighborhood. This exception can be tied to the fact that a large number of customer buildings (1210 customer points to be exact) are located very close to each other in a relatively smaller area in Altınşehir Neighborhood; and correspondingly create a high emission density in that particular region. Another reason for this high emission density could be the distribution of settlements and surrounding green areas in that particular region; however, a more detailed analysis at local level should be performed to investigate this possibility. As an exploratory analysis tool, Kernel Density delivers the global distribution of data; and therefore, does not provide information about statistical significance. Kernel Density maps only reveal the general distribution of emissions within the area of study.

- Other than the above-mentioned exception, in Kernel Density maps, higher $CF_{res,total}$ densities are observed over regions where apartment-type building patterns prevail; and higher Per Capita $CF_{res,total}$ densities are observed over single houses in 19 Mayıs and Altınşehir Neighborhoods.

- As the legends of Kernel Density maps indicate, the emission density ranges of $CF_{res,total}$ are kept constant in all scenarios to better interpret the differences between individual years and also between minimum and maximum scenarios of each year by looking at the movement of $CF_{res,total}$ density patterns. As can be seen in Figure 4-30, in 2017 maximum scenario, the area covered by the highest emission density level **(0.027 – 0.042 tCO_2/m^2)** is the largest while it gradually decreases from 2017 maximum to

2014 minimum. On the contrary, the area covered by the lowest emission density level **(0 – 0.0024 tCO_2/m^2)** is the largest in 2014 minimum scenario and it is the smallest in 2017 maximum scenario.

- The emission density ranges of Per Capita $CF_{res,total}$ are also kept constant in all scenarios to better interpret the differences between scenarios through the movement of Per Capita $CF_{res,total}$ density patterns. As can be seen in Figure 4-38, in 2017 maximum scenario, the area covered by the highest per capita emission density level **(0.0017 - 0.0026 $tCO_2/person/m^2$)** is the largest while it gradually decreases from 2017 maximum to 2014 maximum and it disappears in 2015 and 2014 minimum scenarios. On the contrary, the area covered by the lowest emission density level **(0 – 0.0024 tCO_2/m^2)** is the largest in 2014 minimum scenario and it is the smallest in 2017 maximum scenario. In 2015 minimum scenario, the highest density level is observed as **0.0012 - 0.0017 $tCO_2/person/m^2$** while it decreases to **0.0008 - 0.0012 $tCO_2/person/m^2$** in 2014 minimum.
- Kernel Density maps for mean $CF_{res,total}$ values provided from Figure 4-46 to Figure 4-49 demonstrate a consistent pattern with those of minimum and maximum scenarios. Likewise, in 2017, the area covered by the highest mean emission density level **(0.028 – 0.0419 tCO_2/m^2)** is the largest while it gradually decreases from 2017 to 2014. On the contrary, the area covered by the lowest mean emission density levels **(0 – 0.00035 $tCO_2/person/m^2$)** is the largest in 2014 and the smallest in 2017. Higher mean $CF_{res,total}$ densities are again observed over regions where apartment-type building patterns prevail.
- Kernel Density maps for mean Per Capita $CF_{res,total}$ values provided from Figure 4-50 to Figure 4-53 demonstrate a consistent pattern with those of minimum and maximum scenarios although there is a slight variance due to differently determined emission density ranges. Likewise, in 2017, the area covered by the highest mean per capita emission density level **(0.0012 – 0.00256 $tCO_2/person/m^2$)** is the largest while it gradually decreases from

2017 to 2014. On the contrary, the area covered by the lowest mean emission density level **(0 – 0.0026 tCO_2/m^2)** is the largest in 2014 and the smallest in 2017. Higher mean Per Capita $CF_{res,total}$ densities are again observed over single houses in 19 Mayıs and Altınşehir Neighborhoods.

- According to the Kernel Density maps for COV of $CF_{res,total}$ and Per Capita $CF_{res,total}$ provided from Figure 4-46 to Figure 4-53, the variability between minimum and maximum scenarios is the greatest in 2014 while it gradually decreases from 2014 to 2017. In 2014, where the level of variability is the highest, COVs mostly concentrate over single houses; and especially those over Altınşehir Neighborhood, due to the large number of customer buildings being located very close to each other in a relatively smaller area (see Figure 4-49). In 2015, the level of variability decreases, but the highest variability is again concentrated over single houses in Altınşehir and 19 Mayıs. In 2016 and 2017, the level of variability decreases even more. In 2016, the variability density is still observed over the single houses, while in 2017, it shifts to regions where apartment-type building patterns prevail. This might be due to the fact that all SH-type sample buildings were occupied in 2017 and the slight variability observed between minimum and maximum scenarios occurred only due to the minor vacancy ratio of apartment-type buildings.
- The COV density maps, together with the mean, minimum and maximum emission density maps and hot spot analyses collectively support and demonstrate the previously mentioned statement that the difference between "minimum" and "maximum" scenarios is only noticeable in 2014 and 2015, which is mostly concentrated over single houses in most of the results; and only minor differences are observed in 2016 and 2017.

With the above interpretations of the performed analyses, deriving policy implications becomes possible. Since Per Capita CF is a parameter that better expresses the life style and living standards, it is a more appropriate approach to derive policy implications through Per Capita $CF_{res,total}$. There is a substantial

Per Capita $CF_{res,total}$ difference between apartment-type buildings and single houses (especially those located in 19 Mayıs Neighborhood). As the housing preference evolves from multi-storey apartment buildings to suburban single houses and the living standards increase, consumption differences arise and corresponding Per Capita $CF_{res,total}$ differences occur. To be more specific, in 2017, the Per Capita $CF_{res,total}$ of 19 Mayıs single houses ranged from **1.66 to 11.92 tCO_2/person** while the Per Capita $CF_{res,total}$ of apartment-type customer buildings and Altınşehir single houses ranged from **0.10 to 4.35 tCO_2/person** (see Figure 4-13 and Figure 4-14). These Per Capita $CF_{res,total}$ values of suburban single houses also distinctly differ from the 2017 Per Capita $CF_{res,total}$ value of the area of study calculated as 1.27 tCO_2/person (see Table 4-2) and the 2016 value of Bursa calculated in Bursa SECAP (2017) as 1.04 tCO2/person (see Table 2-6). Accordingly, the policy implications for a reduced CF in the residential sector are provided below:

- **Taxing:** Considering the substantially higher Per Capita $CF_{res,total}$ values of suburban single houses, taxing might be one of the policies suggested to decision-makers. Similar to the "environmental cleaning tax" in Turkey, a new lifestyle tax such as "residential carbon tax" might be established through which householders with higher Per Capita $CF_{res,total}$ pay higher taxes in line with the "polluter pays principle". Taxing may potentially help decrease the consumption amounts of suburban single house dwellers. Furthermore, the revenue generated through this taxing mechanism may be invested in CF reduction projects, which might also be beneficial for municipalities.

- **Regulation:** Regulation during licensing of new single houses might also be a policy tool for reduced Per Capita residential CF, which can either be adopted together with or as an alternative to taxing, depending on the decision-makers. Considering the high Per Capita $CF_{res,total}$ values of suburban single houses, regulations might be established to stimulate passive or active design strategies for single houses to be built.

Accordingly, insulation and energy efficiency design standards may be established to be complied with during the construction and occupancy permit processes. In addition, certain emission standards may be set and demonstration of compliance with these standards may be stipulated for obtaining the construction and occupancy permits.

- **City and Regional Planning:** As observed in Kernel Density Maps provided in Figure 4-38 to Figure 4-45 the Per Capita $CF_{res,total}$ density over the single houses in Altınşehir Neighborhood is high although their Per Capita $CF_{res,total}$ values were classified as low. This high density occurs as a result of the large number of customer buildings located very close to each other in a relatively smaller area. This might be a useful outcome to city and regional planners; and planning of single houses this close to each other in narrow spaces may be avoided if lower per capita CF densities are aimed in a particular region. On the other hand, the $CF_{res,total}$ density is higher over the regions where apartment-type buildings prevail. Construction of more green buildings might be planned to reduce resource consumption and increase energy efficiency, if lower CF densities are aimed in such regions.

3.6 Comparison of Different Residential Heating Systems Based on Their Carbon Footprints

In this section, environmental performances of DH-, CH- and IH-type residential heating systems were compared based on their Per Capita CF due to residential natural gas consumption (Per Capita $CF_{res,NG}$) for the “2017 maximum” scenario. To do so, the same approach for spatial analyses was followed to observe the differences in Per Capita $CF_{res,NG}$ of different building types studied in this thesis and to seek policy implications. In order to better understand the performance of different building types, first, the map in Figure 4-54 was created to develop familiarity with the distribution of building types within the area of study. After providing the building type distribution, statistical and spatial analyses were conducted. The results and discussions are provided further in this section.

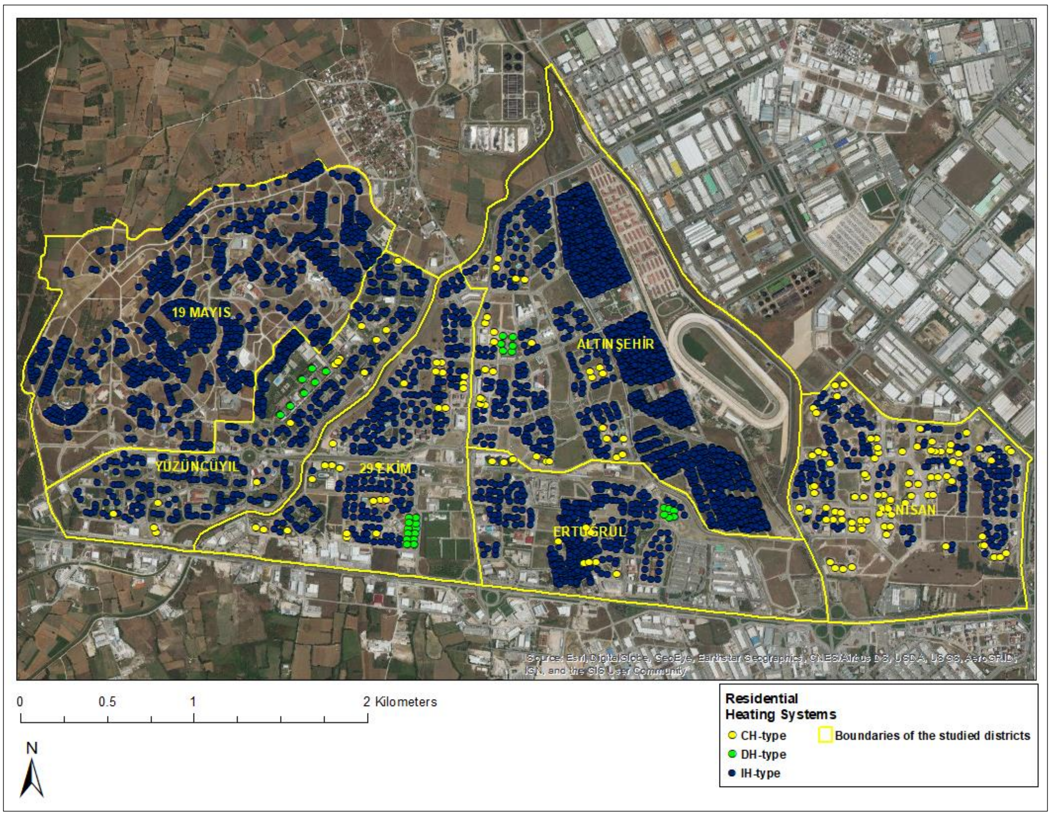


Figure 4-54. Distribution of Different Building Types within the Area of Study

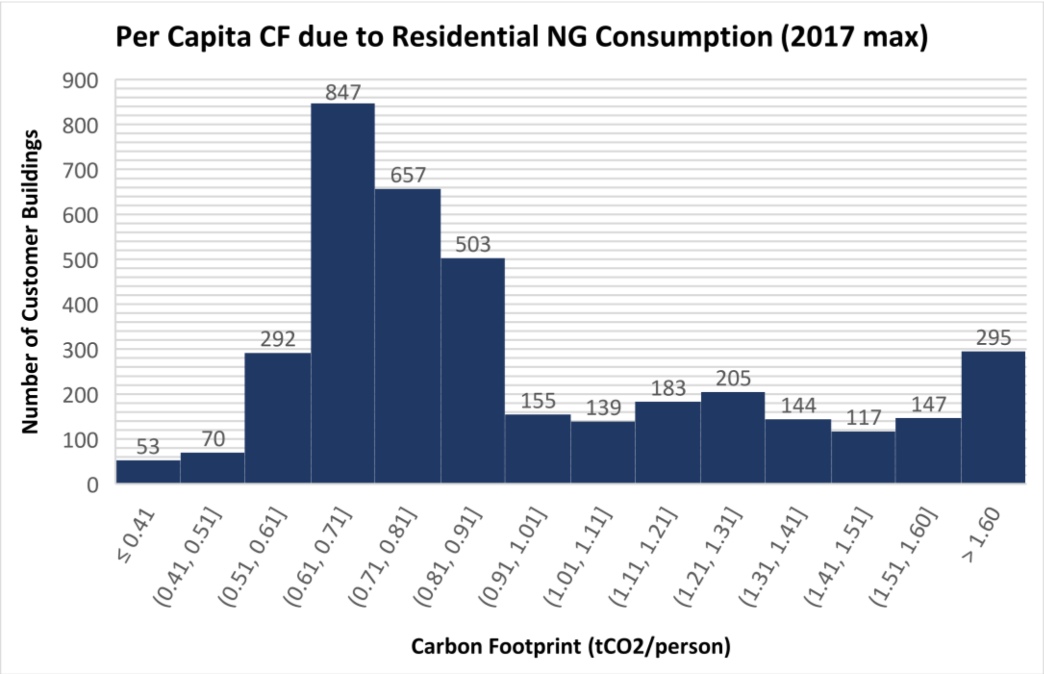


Figure 4-55. Histogram Graph for Per Capita CFres,NG

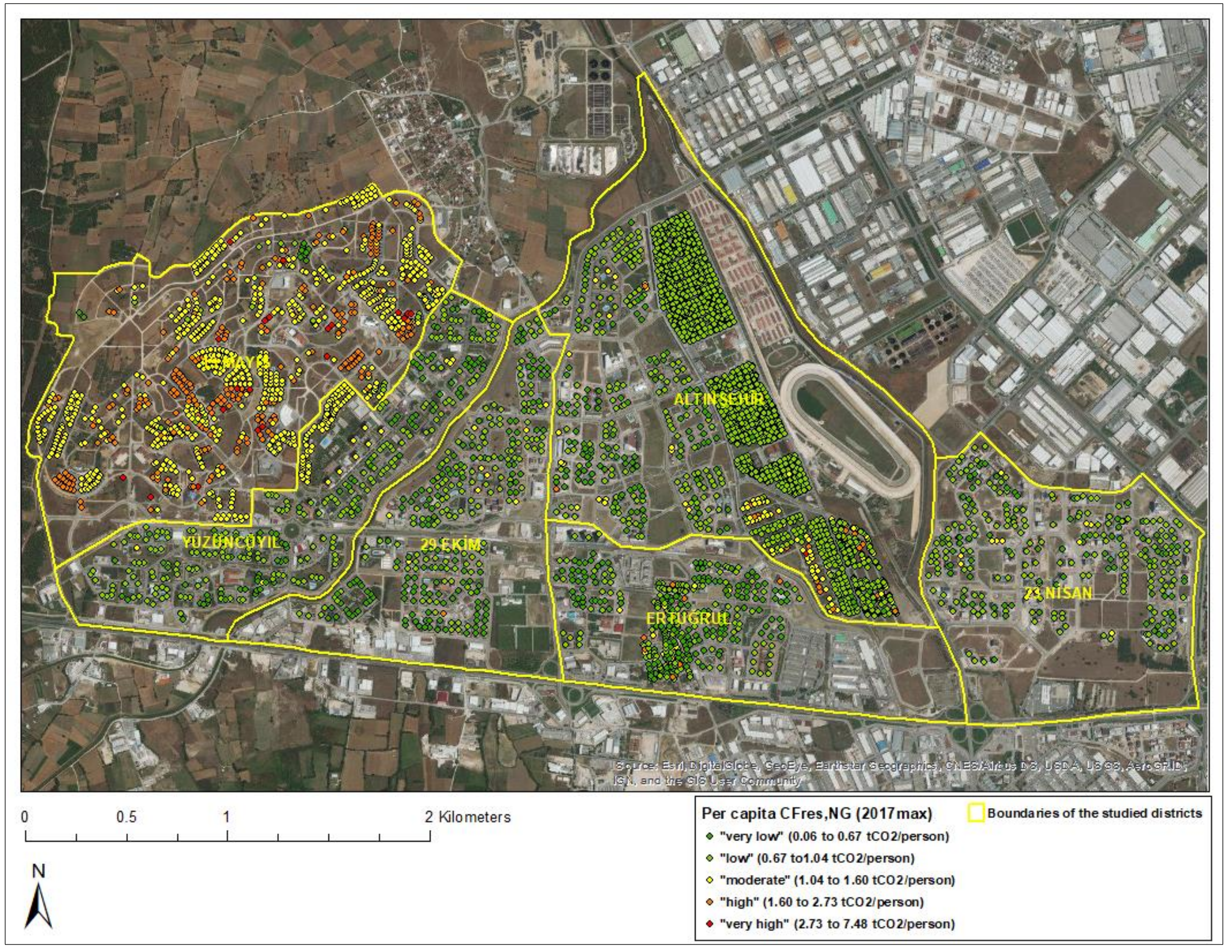


Figure 4-56. Classification of Customer Point Emissions for Per Capita CFres,NG (2017 max)

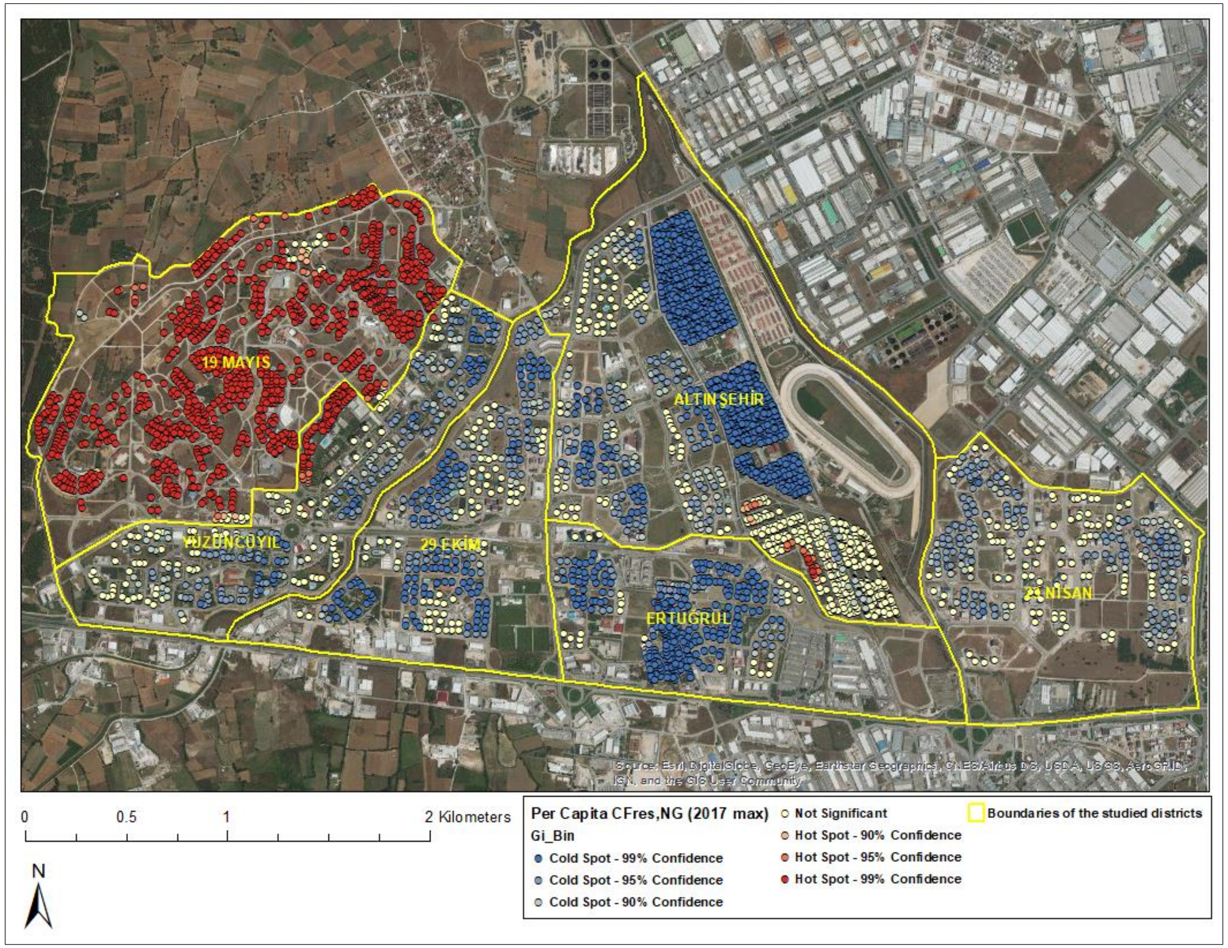
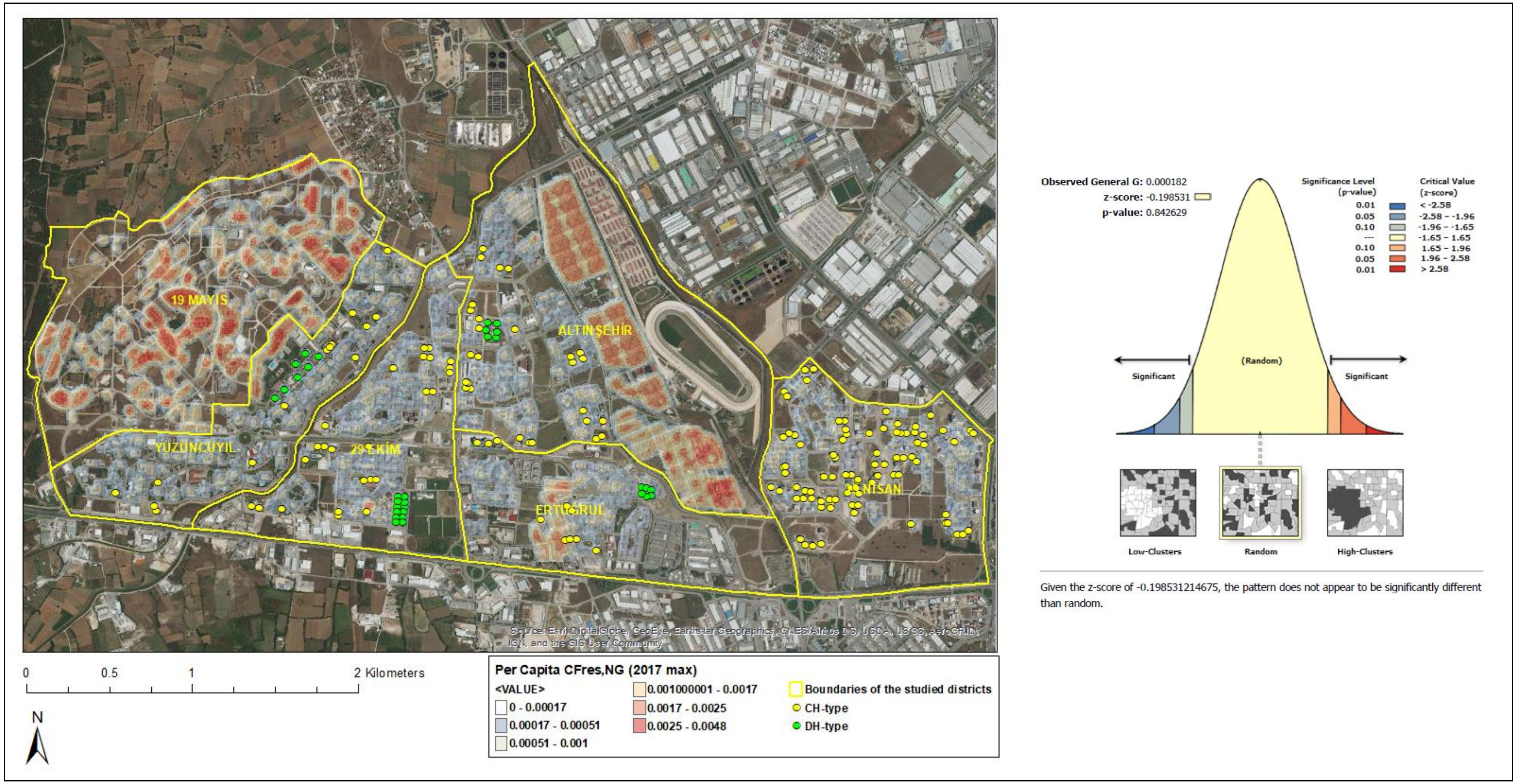


Figure 4-57. Hot Spot Analysis for Per Capita CFres,NG (2017 max)



**It should be noted that the search radius (bandwidth) of the Kernel Density map was taken as 50 m for this case to increase the level of detail.*

Figure 4-58. Kernel Density Map for Per Capita CFres,NG (2017 max)

The comments and discussions of the above statistical and spatial analyses can be listed as follows:

- According to the histogram graph in Figure 4-55, the value range (i.e. the bin) for Per Capita $CF_{res,NG}$ where the largest number of data points are collected is **"0.61-0.71 tCO_2/person"** with 847 customer points in 2017. It is closely followed by **"0.71 – 0.81 tCO_2/person"** bin with more than 657 customer points.

- The classification map provided for Per Capita $CF_{res,NG}$ in Figure 4-56 provides a similar distribution of emission classes to the maps for Per Capita $CF_{res,total}$ in the previous section. It can clearly be seen that the, "*moderate", "high"* and *"very high"* per capita residential emission classes are mostly accumulated in 19 Mayıs single houses, all of which have IH-type residential heating system. It can also be seen that a few single houses located near the Ertuğrul boundary of Altınşehir Neighborhood are also represented with yellow, orange and red dots, which are also IH-type buildings. In general, it is certain that all customer buildings with *"high"* (orange) and *"very high"* (red) Per Capita $CF_{res,NG}$ are IH-type buildings. All of the CH-type buildings on the map are represented with either light green or dark green; and therefore, have either *"low"* or *"very low"* Per Capita $CF_{res,NG.}$ As for the DH-type buildings, most of them are represented with dark green (i.e. *"very low"* Per Capita $CF_{res,NG}$) with the only exception of Saygınkent Complex represented with yellow dots (i.e. *"moderate"* Per Capita $CF_{res,NG}$).

- It can be seen in the hot spot analysis maps presented in Figure 4-57 that all of the statistically significant hot spots with high Per Capita $CF_{res,NG}$ values cluster in IH-type buildings while the CH- and DH- type buildings are mostly represented with cold spots (i.e. lower Per Capita $CF_{res,NG}$ values).

- The Kernel Density map provided in Figure 4-58 indicates that, higher Per Capita $CF_{res,NG}$ densities **(0.0017 – 0.0048 tCO_2/m^2)** are observed over single houses, all of which have IH-type residential heating system. There are also two small regions in Ertuğrul and 29 Ekim Neighborhoods that have higher Per Capita $CF_{res,NG}$ densities, where IH-type buildings are located mostly. On the other hand, CH- and DH- type buildings are mostly within the lower density regions **(0 – 0.0017 tCO_2/m^2)**.

- Considering all the results mentioned above, it can be concluded that CH- and DH-type buildings are more energy-efficient than IH-type buildings and result in lower per capita CF due to residential natural gas consumption.

CHAPTER 5

CONCLUSIONS

4.1 Summary and Findings

In this study, the main objective was to develop a GIS-based CF accounting methodology based on actual electricity and natural gas consumption figures of residential buildings in a pilot area to minimize the limitations caused by deficiencies in CF-related data generation and access; and to contribute to local policy-making by providing useful tools and results to decision-makers. Within this scope, three types of residential heating systems that predominate in Turkey were focused on, namely:

- individual heating (IH) systems,
- central heating (CH) systems, and
- district heating (DH) systems.

The city for the case study was chosen as Bursa, and 7 sample buildings, 4 of them being single-houses, were chosen to be studied on. The actual electricity consumption data of the sample buildings were collected from UEDAŞ, while their actual natural gas consumption data as well as the GIS database of the area were gathered from Bursagaz. Both the electricity and the natural gas consumption data were collected for the 4-year period between 2014-2017. The GIS database was utilized to obtain necessary information about the residential buildings, which are required for CF calculation. The required information included the building type (residential, commercial, etc.), roof and/or floor area, number of floors and type of residential heating system used. The GIS database was initially quite comprehensive and up-to-date; and included valuable information such as:

- the address information,
- type of residential heating system,
- number of dwelling units and work places found within buildings, and
- polygons drawn based on the actual floor area of customer buildings.

However, not all the existing information on the database were complete for all customer buildings; and certain information were still missing; therefore, some further modifications had to be made. By using auxiliary tools such as Google Earth Pro, Google Maps, basemap within the ArcMap and websites of construction firms; and by following assumptions where necessary, the GIS database was turned into a more complete one which would serve the purpose of this study. The identified deficiencies of the initial GIS database were as follows:

- The type of buildings (if they are residential, public, commercial, etc. buildings) were not indicated in the GIS database, which is an important data for differentiating between the sub-categories of urban CF. In this study, the buildings were differentiated into two classes as "residential" and "non-residential", which was sufficient within the scope of this study.
- The residential heating systems were denoted; but only as "IH" and "CH". The DH-type buildings were also "CH" in the database. This had to be modified by assigning "DH" to an assumed percentage of "CH" buildings.
- The polygons that represent the actual floor areas of buildings were not accurate or complete for all buildings. The shapes of such polygons were corrected or re-drawn by using Google Earth and basemap.
- The number of floors were not indicated in the GIS database, which was a crucial information to calculate the CF of a building. This information was added one-by-one for each customer building by using the Street View tool of Google Earth Pro, Google Maps and websites of construction firms

After the completion of database, 3807 out of 4323 customer buildings were identified as "residential buildings". The distribution of 3807 residential buildings by type is provided in Figure 5-1 and by residential heating system is shown in Figure 5-2 below.

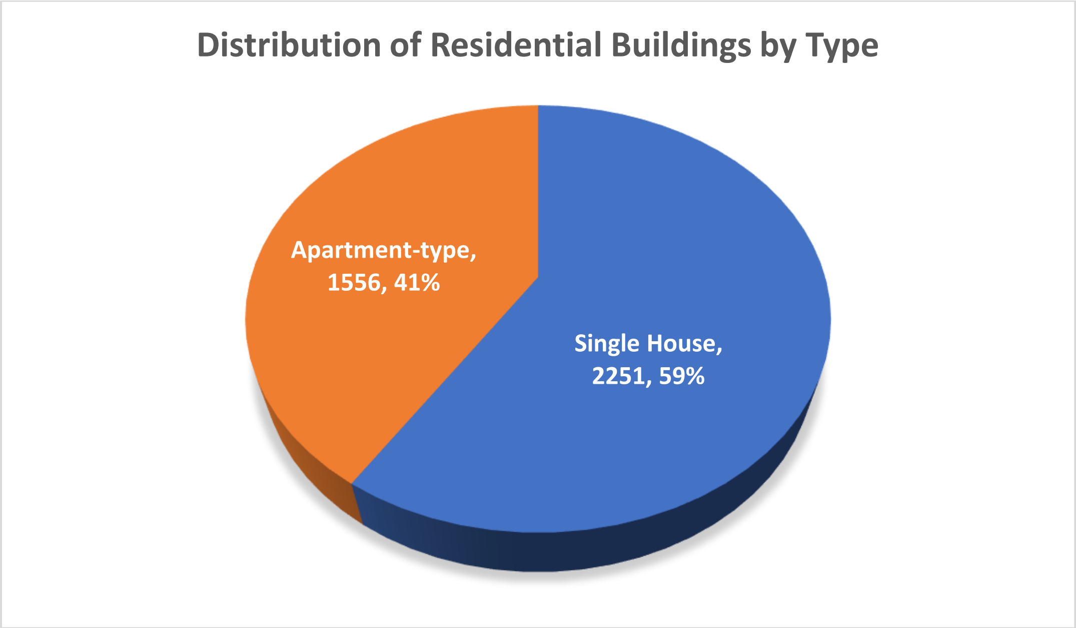


Figure 5-1. Distribution of Residential Buildings by Type

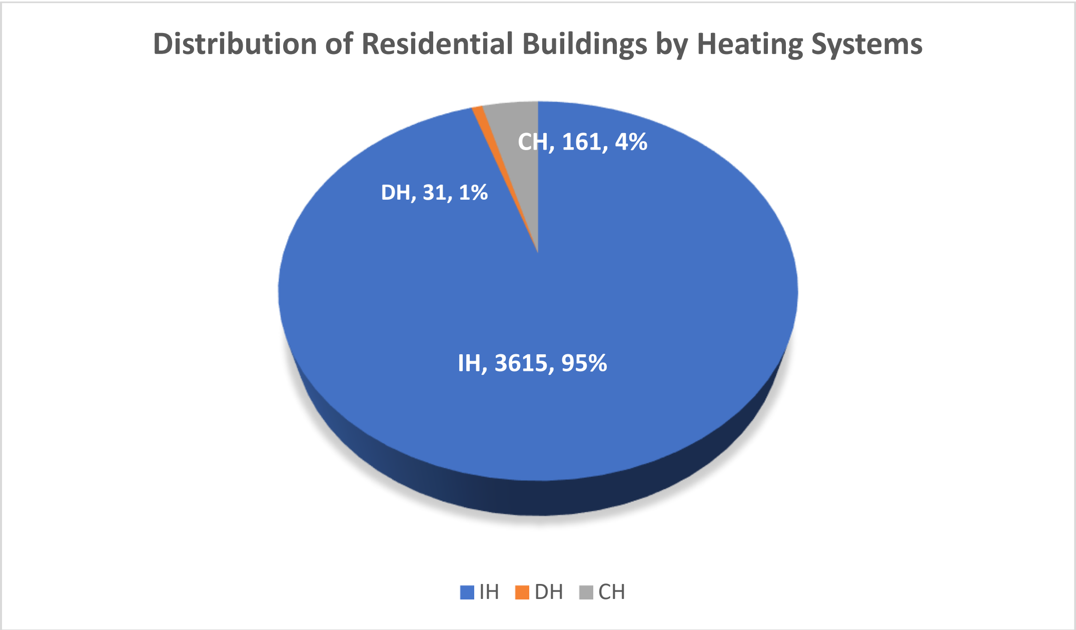


Figure 5-2. Distribution of Residential Buildings by Residential Heating Systems

Subsequently, the unit area-based natural gas and electricity consumptions of sample IH-, CH- and DH-type buildings and sample single houses were calculated. With this unit area-based consumptions and by using the completed GIS database, residential CF in the area of study was estimated for 8 different scenarios. Some key findings from the calculation results are listed below:

- The highest unit area-based natural gas consumptions belong to SH-type buildings, in which IH-type heating systems are used. The general average of unit area-based natural gas consumption (i.e. the four-year average of all scenarios included) of SH-type buildings were calculated as **7.25 Sm^3/m^2**. The second highest consumptions belong to IH-type buildings; and CH- and DH- type buildings had lower unit area-based natural gas consumptions. The lowest figures were those of DH-type buildings since they are more efficient heating systems.
- IH-type buildings had the highest unit area-based electricity consumptions with the general average of **20.00 kWh/m^2**. The general averages of DH, CH and SH-type buildings were quite close to each other with **16.94, 16.84** and **16.74 kWh/m^2**, respectively.
- The per capita $CF_{res,total}$ ranged from **0.99** to **1.27 tCO_2/person** between 2014-2017, with an increasing trend through years. The general average of per capita $CF_{res,total}$ is calculated as **1.15 tCO_2/person.**
- The $CF_{res,total}$ ranged from **93.14** to **119.52 $ktCO_2$** between 2014-2017, with an increasing trend through years. The general average of $CF_{res,total}$ is calculated as **108.04 $ktCO_2$,**

As the last part of the study, a more in-depth analysis of the results of the residential CF calculations was performed through statistical and spatial analyses in Excel and ArcGIS. In addition to allowing for further discussions of results, this step was also intended to contribute to local policy-making by providing beneficial tools and outcomes to decision-makers. Accordingly, histogram graphs, classification maps, hot spot analysis and kernel density maps were created for $CF_{res,total}$ and Per Capita $CF_{res,total}$ for each scenario. Afterwards, these analyses were also implemented for Per Capita CF due to residential natural gas consumption (Per Capita $CF_{res,NG}$) to compare the environmental performances of DH, CH and IH-type residential heating systems for the “2017 maximum” scenario only. Density maps of mean values (i.e. average of minimum & maximum scenarios) and COV were then provided for each year to better demonstrate the scale of difference between minimum and maximum scenarios through years and detect where the average values and COVs concentrated. Some key findings from the statistical and spatial analyses results are listed below:

- The classification maps for $CF_{res,total}$ indicated that the dark green dots that refer to *"very low"* emission class represent the single houses located in 19 Mayıs and Altınşehir Neighborhoods. In contrast, the higher the number of floors and the wider the floor area became, the higher the $CF_{res,total}$ of a particular building became. Likewise, the emission classes in between were represented with apartment-type buildings with different number of floors and various floor areas.
- The classification maps provided for Per Capita $CF_{res,total}$ provide a completely different distribution of emission classes. It was observed that the "*moderate", "high"* and *"very high"* per capita residential emission classes were mostly accumulated in 19 Mayıs single houses. It was also seen that the Per Capita $CF_{res,total}$ values represented with red dots were mostly found in 19 Mayıs single houses; and they were approximately 4-5 times the average Per Capita $CF_{res,total}$ values calculated in this study and also in the GHG inventories prepared for Bursa.
- Hot spot analysis maps showed that high $CF_{res,total}$ values cluster in apartment-type buildings located in Yüzüncüyıl, 29 Ekim, Altınşehir and 23 Nisan Neighborhoods while the cold spots cluster in single houses located in 19 Mayıs and Altınşehir Neighborhoods. On the other hand, the maps for Per Capita $CF_{res,total}$ indicated that hot spots mostly cluster in 19 Mayıs Single houses; and a few single houses located near the Ertuğrul boundary of Altınşehir Neighborhood, in line with the previous classification maps.
- The results of Kernel Density maps were consistent with previous classification maps and hot spot analysis maps in general, except for the Per Capita $CF_{res,total}$ density over the single houses in Altınşehir Neighborhood.

This exception was tied to the fact that a large number of customer buildings are located very close to each other in a relatively smaller area; and thus, generate a high emission density in that particular region. Other than this exception, higher $CF_{res,total}$ densities are observed over regions where apartment-type building patterns prevail; and higher Per Capita $CF_{res,total}$ densities are observed over single houses.

Based on the results of the statistical and spatial analyses, certain policy implications were derived such as taxing and regulation for householders with higher per capita CF, in line with the "polluter pays principle". Finally, a few recommendations for city and regional planning were made.

4.2 General Recommendations for Policy making

In addition to the more specific policy implications derived from the statistical and spatial analyses performed, rather general recommendations for policy-making might be derived. Some recommendations were directly to this study while some were indirect results of the study; however, both were provided below to approach the implications from a wider perspective:

- Energy resources used for residential heating purposes might be switched from fossil fuels to renewables by also considering the renewable energy potential within the region. For example, solar PV panels may be installed on the roofs of single houses.
- Electricity grid should also be fed by a larger amount of electricity generated by renewables. More geothermal and wind energy resources of the region should be utilized and fed to the electricity grid.
- "Greener" approaches might be followed and adopted during residential building design and city and regional planning. For example, number of green buildings might be increased and regulation during licensing of new apartment-type buildings might be considered as a policy tool for reduced residential CF. Accordingly, insulation and energy efficiency design

standards may be established to be complied with during the construction and occupancy permit processes. In addition, certain emission standards may be set and demonstration of compliance with these standards may be stipulated for obtaining the construction and occupancy permits.

- As the results in Section 3.6 also emphasize, CH- and DH-type buildings are more energy-efficient than IH-type buildings and result in lower per capita CF due to residential natural gas consumption. Accordingly, shifting from IH-type residential heating systems to CH- and DH-type systems in both single and apartment-type residential buildings might be offered.
- As also identified some of the former inventories summarized in Table 2-6, problems regarding data quality and elaboration are commonly encountered during data acquisition from municipal and non-municipal institutions, due to inadequate human resource capacity and deficient datasets. To overcome such problems, human resource capacity in these institutions might be improved and identified deficiencies in GIS database should be eliminated. The most important deficiencies identified, and the suggested solutions include the following:
    - The purpose of use of each building should be identified on the database as “residential”, “commercial”, “public” etc. Mixed-used buildings might also be specified.
    - Information about the number of dwelling units and workplaces within buildings were not complete and inconsistencies were observed. Such information should be up-to-date and complete within the database to avoid miscalculations.
    - Actual floor areas of buildings should be drawn by distinguishing the regular floor areas from the stores at the ground floor. Furthermore, actual residential area (excluding the common spaces etc.) might also be specified for each building.
    - Accurate number of floors of each building should be identified on the database,

   - DH-type residential heating systems should also be identified on the GIS database,
   - Single houses should be identified on the database,
   - Construction date and vacancy ratio of each building might be followed and integrated into the database,
   - Information about the energy efficiency measures in buildings, such as insulation, might be added to the database, if any.
- The contributions of GIS and spatial analyses to visualization and better interpretation of results were clearly observed; and the methodology developed in this study is considered as a useful carbon inventorying and monitoring tool. It can be utilized in the context of current climate policies, especially by local administrations. Each municipality might have their own dataset; and even better outcomes might be obtained if municipalities have their own, continuously self-updating and complete GIS database without the mentioned deficiencies in this study.
- City administrations and utility providers (such as natural gas and electricity distribution companies like Bursagaz and UEDAŞ) should establish and use a common dataset. Furthermore, continuous and cooperative updating of such dataset would significantly contribute to the solution of data acquisition issues during inventorying and monitoring.
- If this methodology is adopted and improved by municipalities, emission limits might be set and integrated into the continuously self-updating system. Hence, real-time monitoring of the emissions might be possible and timely interventions may be enabled when the limit is exceeded.

4.3 Recommendations for Future Research

Based on the limitations and difficulties observed during this study, it is firstly recommended for future research to obtain actual residential area instead of the floor area of buildings to obtain more accurate results. As previously mentioned, buildings' floor areas were used since actual residential area data were not publicly available and it could not be obtained from the GIS database used in this study.

A default emission factor for natural gas consumption had to be used due to the lack of country or region-specific emission factor. Likewise, the national electricity grid emission factor for Turkey was used due to the lack of an emission factor specific to Nilüfer District or Bursa Province. It is recommended for further research to use specific emission factors to increase the accuracy of CF calculation results.

A limited number of representative sample buildings could be used in this study due to time limitation as well as community's privacy concerns and reluctance to data sharing. Therefore, another recommendation would be using more sample buildings to obtain more representative consumption data and correspondingly more accurate unit area-based consumption values by minimizing the error margin.

The average household population data for Bursa was used in this study for obtaining the Per Capita CF results due to the lack of household population data specific to district or building type. However, a more representative household population data specific to the district or even specific to the building types might be more useful in future studies.

The convenience of using a GIS software in CF accounting was observed in this study; however, the initial GIS database had to be further modified to obtain a complete GIS database that would serve the purpose of this study. Therefore, it is recommended that municipalities have their own, up-to-date and complete GIS database to be used for practical and accurate CF calculations.

The high Per Capita emission density over the single houses in Altınşehir was tied to the large number of buildings located densely in a small area. There might also be other reasons for this high emission density, such as the distribution of settlements and surrounding green areas in that particular region; however, a more detailed analysis at local level should be performed to investigate this possibility.

If the GIS database of whole Bursa Province could be obtained and a correlation between emissions and parcels within the database could be established, the residential CF of Bursa could be derived from the pilot area. Hence, future research might focus on deriving the CF of a city from a pilot area by establishing appropriate correlations.

This methodology may also be modified to be used for other sectors than the residential sector. Future research may focus on using this methodology to calculate the CF due to other sectors such as waste generation or transportation; and thus, obtain the complete urban CF of a city.

REFERENCES

A Definition of Carbon Footprint2008Nova Science Publishers

A GIS-based approach for estimating land use related carbon emissions — A case study in Henan Province2013*International Conference on Geoinformatics*1-4doi10.1109/Geoinformatics.2013.6626023

An assessment of the CO2 emissions reduction in high speed rail lines: Two case studies from Turkey2017*Journal of Cleaner Production165*746-761doihttps://doi.org/10.1016/j.jclepro.2017.07.045

Asdrubali, F., Presciutti, A., & Scrucca, F. (2013, October). Development of a greenhouse gas accounting GIS-based tool to support local policy making - application to an Italian municipality. *Energy Policy, 61*, 587–594. doi:https://doi.org/10.1016/j.enpol.2013.05.116

2017*Auckland's Greenhouse Gas Inventory to 2015*Auckland CouncilAucklandAuckland Council

Australia's Carbon Footprint*Economic Systems Research21*3243-266doi10.1080/09535310903541397

Bakhshi, A. A., & deMonsabert, S. M. (2009). A GIS Methodology for Estimating the Carbon Footprint in Municipal Water and Wastewater in Fairfax County, Virginia. *Energy Engineering, 106*(5), 7-24. Retrieved from https://www.tandfonline.com/doi/abs/10.1080/01998590909594541

Bayindir Municipality. (2017). *Bayindir District Urban Greenhouse Gas Inventory (Carbon Footprint) and Analysis Project.* Izmir. Retrieved from http://www.skb.gov.tr/wp-content/uploads/2017/10/Bayindir-Karbon-Ayak-Izi-Analizi-1.pdf

Biomass Burning Emission Inventory from Remote Sensing, GIS and Ground Based Measurements - A Case Study from Secondary Mixed Deciduous Forests, India2002*Geocarto International17*2doi10.1080/10106040208542231

British Standard Institution2011*PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*

BSI2014*Application of PAS 2070 – London, United Kingdom* LondonThe British Standards Institution

BSI2014*PAS 2070:2013 + A1:2014 Specification for the assessment of greenhouse gas emissions of a city*LondonThe British Standards Institution

Bureau of Environment. (2018). *Final Energy Consumption and Greenhouse Gas Emissions in Tokyo (FY 2015).* Tokyo Metropolitan Government, Tokyo. Retrieved from http://www.kankyo.metro.tokyo.jp/en/climate/index.files/GHG2015.pdf

Bursa Metropolitan Municipality2015*Bursa Metropolitan Municipality Corporate and Urban Carbon Footprint Inventory*BursaBursa Metropolitan Municipality

Bursa Metropolitan Municipality2017*Bursa Sustainable Energy and Climate Action Plan*Bursa Metropolitan Municipality Directorate of Environmental Protection and ControlBursaBursa Metropolitan Municipality

C40 Cities2012*Why Cities?*

C40 Cities2017*City greenhouse gas emissions interactive dashboard*

C40 Cities. (2018). Retrieved from Global Leadership on Climate Change: http://www.c40.org/

Cankaya Municipality External Relations Department. (2017). *Cankaya Municipality Sustainable Energy Action Plan* . Cankaya Municipality.

Ankara: Cankaya Municipality. Retrieved from http://www.skb.gov.tr/wp-content/uploads/2017/12/Cankaya-SEEP-Raporu-05.06.2017.pdf

Carbon footprints and embodied carbon at multiple scales2010*Current Opinion in Environmental Sustainability*245-250

CDM2018*Approved Baseline and Monitoring Methodologies for Large Scale CDM Project Activities*

CDP2013*CDP Cities 2013 Buenos Aires*CDP

CDP. (2013). *CDP Cities 2013 City of Melbourne.* CPD. Retrieved from https://www.c40.org/

CDP2015*CDP Cities 2015 Durban*Durban

CDP2015*CDP Cities 2015 Oslo*CDP

Chavez, A., & Ramaswami, A. (2013, March). Articulating atrans-boundary infrastructure supply chain greenhouse gas emission footprint for cities: Mathematical relationships and policy relevance. *Energy Policy, 54*, 376–384. Retrieved August 21, 2017, from https://www.sciencedirect.com/science/article/pii/S0301421512009184?via%3Dihub

Chavez, A., Ramaswami, A., Dwarakanath, N., Guru, R., & Kumar, E. (2012). Implementing Trans-Boundary Infrastructure-Based Greenhouse Gas Accounting for Delhi, India. *Journal of Industrial Ecology, 16*(6), 814-828. doi:10.1111/j.1530-9290.2012.00546.x

City of Los Angeles2017Community-Wide Greenhouse Gas Emissions Los Angeles

Compact of Mayors2016*Global Impact of the Compact of Mayors*

Covenant of Mayors. (2010). Part II Baseline Emissions Inventory. In *How to develop a Sustainable Energy Action Plan (SEAP) - Guidebook* . Luxembourg.

Covenant of Mayors. (n.d.). *Covenant Community: Signatories*. Retrieved from Covenant of Mayors for Climate and Energy: http://www.covenantofmayors.eu/about/covenant-community/signatories.html

Covenant of Mayors. (n.d.). *Flashback: The origins of the Covenant of Mayors*. Retrieved from Covenant of Mayors for Climate and Energy: http://www.covenantofmayors.eu/about/covenant-initiative

Dalvi, M., Beig, G., Patil, U., Kaginalkar, A., Sharma, C., & Mitra, A. P. (2006). A GIS based methodology for gridding of large-scale emission inventories: Application to carbon-monoxide emissions over Indian region. *Atmospheric Environment, 40,* 2995–3007. doi:10.1016/j.atmosenv.2006.01.013

Delivand, M. K., Cammerino, B. A., Garofalo, P., & Monteleone, M. (2015, July 15). Optimal locations of bioenergy facilities, biomass spatial availability, logistics costs and GHG (greenhouse gas) emissions: a case study on electricity productions in South Italy. *Journal of Cleaner Production, 99,* 129-139. doi:https://doi.org/10.1016/j.jclepro.2015.03.018

Demir Enerji. (2016). *Maltepe Municipality Sustainable Energy Action Plan.* Istanbul: Maltepe Municipality. Retrieved from http://mycovenat.registrationforms.balanced.karakas.prvw.eu/about/signatories_en.html?city_id=7650&seap

Demir Enerji Danismanlik. (2013). *Antalya Metropolitan Municipality Sustainable Energy Action Plan.* Antalya: Antalya Metropolitan Municipality. Retrieved from http://mycovenant.eumayors.eu/docs/seap/5376_1399535086.pdf

Ecological and carbon footprint by consumption and income in GIS: down to a census village scale*Local Environment16*9871-886doihttps://doi.org/10.1080/13549839.2011.615303

EEA. (2016). *EMEP/EEA air pollutant emission inventory guidebook 2016: Technical guidance to prepare national emission inventories.* Luxembourg: European Environment Agency.

EIB2014*European Investment Bank Induced GHG Footprint - The carbon footprint of projects financed by the Bank - Methodologies for the Assessment of Project GHG Emissions and Emission Variations - Version 10.1*Guideline

EIB2018*The EU Bank*

Embodied Energy and Carbon

EMRA. (2016, October 13). Natural Gas Market Tariff Regulation, Official Gazette numbered 29856 and dated 13.10.2016. Retrieved May 14, 2018, from http://mevzuat.basbakanlik.gov.tr/Metin.Aspx?MevzuatKod=7.5.22932&MevzuatIliski=0&sourceXmlSearch=Do%C4%9Fal%20Gaz

Energy and carbon embodied in the international trade of Brazil: an input–output approach*Ecological Economics39*409-424

2016*Energy-Related Carbon Footprint Inventory of Bilecik City Centre*Bilecik Municipality

Environment and Climate Change Canada*Canada Gazette Part 1*

EPA*Combined Heat and Power (CHP) Partnership*

Eskisehir Tepebasi Municipality2014*Eskisehir Tepebasi Municipality Sustainable Energy Action Plan*SEAPEskisehir

Esri2018*ArcMap*

Esri. (n.d.). *Data Classification Methods*. Retrieved from ArcGIS Pro: http://pro.arcgis.com/en/pro-app/help/mapping/layer-properties/data-classification-methods.htm

Esri. (n.d.). *Histogram*. Retrieved from ArcGIS Pro: https://pro.arcgis.com/en/pro-app/help/analysis/geoprocessing/charts/histogram.htm

ESRI. (n.d.). *History of GIS*. Retrieved March 17, 2017, from Esri: https://www.esri.com/en-us/what-is-gis/history-of-gis

Esri. (n.d.). *How High/Low Clustering (Getis-Ord General G) works*. Retrieved from ArcGIS Pro: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/h-how-high-low-clustering-getis-ord-general-g-spat.htm

Esri. (n.d.). *How Hot Spot Analysis (Getis-Ord Gi*) works*. Retrieved from ArcGIS Pro: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm

Esri. (n.d.). *Understanding density analysis*. Retrieved from ArcGIS Pro: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/understanding-density-analysis.htm

ESRI. (n.d.). *What is GIS*. Retrieved March 17, 2018, from Esri: https://www.esri.com/en-us/what-is-gis/overview

Estimating the carbon footprint of the municipal water cycle*Journal - American Water Works Association104*5337-347doihttps://doi.org/10.5942/jawwa.2012.104.0064

European Environment Agency2013*European Union CO2 emissions: different accounting perspectives*LuxembourgPublications Office of the European Union

European Environment Agency2016*EMEP/EEA air pollutant emission inventory guidebook 2016*LuxembourgEuropean Environment Agency

Evren, N. E. (2015, September). A Comparative Analysis of Efficiency and Carbon Dioxide Mitigation Potential Of Residential Heating Systems In Bursa (Turkey). Ankara, Turkey.

Fagbeja, M. A., Hill, J. L., Chatterton, T. J., Longhurst, J. W., Akpokodje, J. E., Agbaje, G. I., & Halilu, S. A. (2017, March). Challenges and opportunities in the design and construction of a GIS-based emission inventory infrastructure for the Niger Delta region of Nigeria. *Environmental Science and Pollution Research, 24*(8), 7788–7808. doi:10.1007/s11356-017-8481-z

GEF. (2018). *Greenhouse Gas (GHG) Accounting.* Retrieved January 28, 2018, from Global Environment Facility: https://www.thegef.org/topics/greenhouse-gas-ghg-accounting

GIS-Based Research on Spatial-Temporal Variation Characteristics of Carbon Footprint in Hunan Province from 2000 to 20102012*Agro-Geoinformatics*IEEEdoi10.1109/Agro-Geoinformatics.2012.6311658

Gold Standard2018*Our Purpose*

Greater London Authority2017London Energy and Greenhouse Gas Inventory (LEGGI)LondonUnited Kingdom

Greenhouse gas emissions from cities: comparison of international inventory frameworks*Local Environment17*2223-241

Hedger, M. (2013). The climate change policy process and low carbon development. In F. Urban, & J. Nordensvärd (Eds.), *Low Carbon Development Key Issues* (p. 42). United Kingdom: Routledge.

High resolution inventory of GHG emissions of the road transport sector in Argentina*Atmospheric Environment101*303-311doihttps://doi.org/10.1016/j.atmosenv.2014.11.040

Hillman, T., & Ramaswami, A. (2010, February 5). Greenhouse Gas Emission Footprints and Energy Use Benchmarks for Eight U.S. Cities. *Environmental Science & Technology*, 1902-1910. doi:10.1021/es9024194

ICLEI. (n.d.). Retrieved from ICLEI Local Governments for Sustainability: http://www.iclei.org/

ICLEI2009*International Local Government GHG Emissions Analysis Protocol (IEAP)*

ICLEI USA2017*Greenhouse Gas Protocols*

ICLEI. (n.d.). *What is the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)?* Retrieved September 2017, from ICLEI Local Governments for Sustainability: http://www.iclei.org/activities/agendas/low-carbon-city/gpc.html

Implementing Carbon-Footprint-Based Calculation Tools in Municipal Greenhouse Gas Inventories-The Case of Norway2010*Journal of Industrial Ecology*965-977

Integrating GIS with optimization method for a biofuel feedstock supply chain*Biomass and Bioenergy98*194-205doihttps://doi.org/10.1016/j.biombioe.2017.01.004

Internation Conseil Energie. (2011). *Gaziantep Climate Change Action Plan: Energy and GHG Emissions Profile, Preliminary Action Plan and Implementation Strategy.* Gaziantep.

IPCC20062006 IPCC Guidelines for National Greenhouse Gas Inventories

IPCC. (2017). *Activities*. Retrieved January 2018, from Intergovernmental Panel on Climate Change: https://www.ipcc.ch/activities/activities.shtml

IPCC2018*Emission Factor Database*

ISO*Greenhouse gas emissions - ISO 14067 to enable worldwide comparability of carbon footprint data*

ISO2013*ISO/TS 14067:2013(en) Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification and communication*

İzmir MM Environmental Protection and Control Department . (2016). *Izmir Metropolitan Municipality Sustainable Energy Action Plan.* Izmir: Izmir Metropolitan Municipality. Retrieved from http://www.skb.gov.tr/wp-content/uploads/2017/01/Izmir-Buyuksehir-Belediyesi-Surdurulebilir-Enerji-Eylem-Plani.pdf

Japan Environmental Management Association for Industry. (2013). *JEMAI Environmental Label Program.* Base Document. Retrieved August 2017, from http://www.ecoleaf-jemai.jp/eng/data/JG-01-02.pdf

Kadikoy Municipality2013*Kadikoy Municipality Sustainable Energy Action Plan*

Karsiyaka Municipality. (2012). *Karsiyaka Sustainable Energy Action Plan* . Izmir: Karsiyaka Municipality. Retrieved from http://mycovenant.eumayors.eu/docs/seap/2476_1344588432.pdf

Kauffmann, C., Less, C. T., & Teichmann, D. (2012). *Corporate Greenhouse Gas Emission Reporting: A Stocktaking of Government Schemes.* OECD Working Paper, OECD. Retrieved February 5, 2018, from http://www.oecd-ilibrary.org/finance-and-investment/corporate-greenhouse-gas-emission-reporting_5k97g3x674lq-en

Kuonen, S. (2015, August 10). Estimating greenhouse gas emissions from travel – a GIS-based study. *Geographica Helvetica, 70*(3), 185-192. doi:https://doi.org/10.5194/gh-70-185-2015

Lin, J., Hu, Y., Cui, S., Kang, J., & Ramaswami, A. (2015, April 30). Tracking urban carbon footprints from production and consumption perspectives. *Environmental Research Letters, 10*(5). doi:10.1088/1748-9326/10/5/054001

Lombardi, M., Laiola, E., Tricase, C., & Rana, R. (2017, June 18). Assessing the urban carbon footprint: An overview. *Environmental Impact Assessment Review*, 43-52. doi:10.1016/j.eiar.2017.06.005

2015*Mugla Province 2013 Greenhouse Gas Inventory and Sustainable Energy Action Plan*Mugla Metropolitan Municipality

Nansai, K., Kagawa, S., Kondo, Y., Suh, S., Inaba, R., & Nakajima, K. (2009, September 3). Improving the Completeness of Product Carbon Footprints Using a Global Link Input-Output Model: The Case of Japan. *Economic Systems Research*, *21*(3), 267-290. doi:10.1080/09535310903541587

OECDOECD CO2 emissions embodied in consumptionParis

Pendik Municipality. (n.d.). *Pendik District Carbon Footprint Study*. Istanbul: Pendik Municipality. Retrieved from http://www.skb.gov.tr/wp-content/uploads/2017/01/Pendik-Ilcesi-Karbon-Ayak-Izi.pdf

RA Alternatif Enerji . (2013). *Bornova Municipality Sustainable Energy Action Plan.* Izmir: Bornova Municipality. Retrieved from http://mycovenant.eumayors.eu/docs/seap/2847_1360071053.pdf

RA Alternative Energy2012*Karaman Sustainable Energy Action Plan Survey*Mevlana Development AgencyKaramanRA Alternative Energy

Ramaswami, A., Chavez, A., Ewing-Thiel, J., & Reeve, K. E. (2011, April 26). Two Approaches to Greenhouse Gas Emissions Foot-Printing at the City Scale. *Environmental Science & Technology*, *45*, 4205–4206. doi:10.1021/es201166n

Ramaswami, A., Hillman, T., Janson, B., Reiner, M., & Thomas, G. (2008, April 7). A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories. *Environmental Science & Technology*, *42*(17), 6455-6461. doi:10.1021/es702992q

Ruzgar Danismanlik. (2016). *Bursa Nilufer District SEAP*. Nilufer Municipality. Retrieved from http://www.skb.gov.tr/wp-content/uploads/2017/01/Nilufer-Belediyesi-Surdurulebilir-Enerji-Eylem-Plani.pdf

San Francisco Department of Environment2018San Francisco Department of EnvironmentSan FranciscoSan Francisco Department of Environment

Sánchez-García, S., Athanassiadis, D., Martínez-Alonso, C., Tolosana, E., Majada, J., & Canga, E. (2017, July 20). A GIS methodology for optimal location of a wood-fired power plant: Quantification of available woodfuel, supply chain costs and GHG emissions. *Journal of Cleaner Production, 157*, 201-212. doi:https://doi.org/10.1016/j.jclepro.2017.04.058

Seferihisar Municipality. (2013). *Seferihisar Municipality Sustainable Energy Action Plan.* SEAP, Izmir. Retrieved from http://www.covenantofmayors.eu/about/covenant-community/signatories/action-plan.html?scity_id=4807

TFEIP Secreteriat. (n.d.). *EMEP/EEA Air Pollutant Emission Inventory Guidebook.* Retrieved from Task Force on Emission Inventories & Projections: http://www.tfeip-secretariat.org/emep-eea-guidebook/

The United Nations Economic Commission for Europe 2012*Status of ratification of the 1979 Geneva Convention on Long-range Transboundary Air Pollution as of 24 May 2012*

The World Bank. (2015, November). *International Financial Institution Framework for a Harmonised Approach to Greenhouse Gas Accounting.* Retrieved January 28, 2018, from The World Bank: http://www.worldbank.org/content/dam/Worldbank/document/IFI_Framework_for_Harmonized_Approach%20to_Greenhouse_Gas_Accounting.pdf

TUIK2017*Adrese Dayalı Nüfus Kayıt Sistemi*

Turkish State Meteorological Service2018MEVBİS

Turkish State Meteorological ServiceMEVBİS

Turkish Statistical Instituteİl Bazında Gayrisafi Yurtiçi Hasıla, 2004-2014

Turkish Statistical Institute2017*Average household size by province, 2008-2017*

Turkish Statistical Institute2017Quarterly Gross Domestic Product, IV Quarter: October - December, 2017

UNDP. (2016). *Table 1: Human Development Index and its components*. Retrieved from Human Development Reports: http://hdr.undp.org/en/composite/HDI

UNEP, UN-Habitat and World Bank *Greenhouse Gas Emissions from Cities - Comparison of International Inventory Frameworks*

UNEP, UN-HABITAT, World Bank. (2010, June 28). International Standard for Determining Greenhouse Gas Emissions for Cities.

UNESCO2012*Carbon and Water Footprints*United Nations World Water Assessment ProgrammeParisUNESCO

UNFCCC2014*Climate Finance*

UNFCCC2014*Harvested Wood Products*

UNFCCC2014*Kyoto Protocol*

UNFCCC. (2016, August 16). *First steps to a safer future: Introducing the United Nations Framework Convention on Climate Change*. Retrieved from United Nations Climate Change: http://unfccc.int/essential_background/convention/items/6036.php

UNFCCC. (2017, September 12). *Nationally Determined Contributions (NDCs)*. Retrieved from United Nations Climate Change: http://unfccc.int/focus/items/10240.php

UNFCCC. (2018). *The Paris Agreement* . Retrieved from United Nations Climate Change: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

USGS. (n.d.). *What is a geographic information system (GIS)?* Retrieved March 17, 2018, from US Geological Survey: https://www.usgs.gov/faqs/what-a-geographic-information-system-gis

VCS2017*Who We Are*

WBCSD and WRI2004*The Greenhouse Gas Protocol - A Corporate Accounting and Reporting Standard*

World Bank. (2010, December). CITIES AND CLIMATE CHANGE: AN URGENT AGENDA. Washington DC, USA. Retrieved December 2018, from http://siteresources.worldbank.org/INTUWM/Resources/340232-1205330656272/4768406-1291309208465/PartIII.pdf

WRI and WBCSD2011*The Greenhouse Gas Protocol - Product Life Cycle Accounting and Reporting Standard*

WRI, C40 and ICLEI2014*Global Protocol for Community-Scale Greenhouse Gas Emission Inventories – An Accounting and Reporting Standard for Cities*World Resources Institute

WRI, C40, ICLEI2014*Global Protocol for Community-Scale Greenhouse Gas Emission Inventories - Executive Summary*

Yajie, D., Beicheng, X., & Weidong, C. (2014, December). Carbon footprint of urban areas: An analysis based on emission sources account model. *Environmental Science & Policy*, *44*, 181-189. doi:https://doi.org/10.1016/j.envsci.2014.07.013

Yao, H., Wen, Z., Xunhua, Z., Shenghui, H., & Yongqiang, Y. (2006, April). Estimates of methane emissions from Chinese rice paddies by linking a model to GIS database. *Acta Ecologica Sinica*, *26*(4), 980-988. doi:https://doi.org/10.1016/S1872-2032(06)60016-4

Zhang, F., Johnson, D., Johnson, M., Watkins, D., Froese, R., & Wang, J. (2016, January). Decision support system integrating GIS with simulation and optimisation for a biofuel supply chain. *Renewable Energy*, *85*, 740-748. doi:https://doi.org/10.1016/j.renene.2015.07.041

APPENDIX A

BASICS OF EMISSIONS ACCOUNTING

Accounting Perspectives

1. Territorial Perspective

Territorial perspective takes into account the emissions released from within the boundaries of a city or country; and from the areas that are under the jurisdiction of that city or country. Scope 1 and Scope 2 emissions are accounted while urban emissions arising from national and international trades are excluded. Territorial perspective was originally developed to account for the emissions of a region or country; and to set the necessary mitigation measures accordingly.

According to the European Environment Agency (EEA), territorial perspective is the only perspective that has been acknowledged by the international environmental law to constitute a country's emissions and mitigation efforts. In the European Union (EU), territorial emission datasets that focus on the physical location of emissions are also used as the basis for the atmospheric modelling applications. Territorial perspective is adopted in emission inventories linked to international conventions such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Long-range Transport of Air Pollution (CLRTAP), as well as in scientific inventories supporting studies for emissions impact modelling purposes.

Quantifying territorial emissions is known as “emission inventorying”, which also requires accounting for emissions within the system boundaries defined by the related environmental legislation. System boundaries determine what types of emissions are accounted for, which is dependent upon the purpose of the territorial emissions accounting. Emission inventorying can be defined as a process for quantifying the amount of GHGs emitted by individual or groups of emission sources within a particular geographic area over a specific period. The process is implemented through specific monitoring and calculation methodologies. Emission inventories are compiled for various reasons, which are listed as follows:

1. meeting the reporting requirements under international agreements and the EU legislation,
2. contributing to the assessment studies on drivers, trends, and projections of emissions; and
3. supporting the local, regional and global climate modelling studies to estimate the environmental impacts of air emissions, which require more detailed data (European Environment Agency, 2013) (Lombardi, Laiola, Tricase, & Rana, 2017).

2. Production-Based Perspective

Production-based perspective comprises all emissions arising due to the economic activities (i.e. production) of resident companies and households; irrespective of the location where their production activities take place. In other words, emissions from the activities of actors that have their economic interest within the economic borders of the selected region are accounted even if they maintain their production activities abroad. Unlike the territorial perspective, economic borders of a region are focused on here, rather than geographic or jurisdictional borders. Therefore, the accounted emissions include certain Scope 3 emissions in addition to Scope 1 and 2 emissions. The included Scope 3 emissions are specifically the embodied emissions[5] resulting from the export activities (European Environment Agency, 2013) (Lombardi, Laiola, Tricase, & Rana, 2017) (McAlinden, 2015).

[5] Embodied emissions are defined as the life cycle emissions that occur along the supply chain of a functional unit via the production network. Therefore, “carbon footprint” and “embodied emissions” are synonyms under consistent definitions (Peters, 2010).

3. Consumption-Based Perspective

Consumption-based (or demand-based) accounting perspective covers the emissions resulting from the consumption of fuels, goods and services within the chosen boundaries; regardless of the place where these goods and services are produced. In other words, it includes emissions from the consumption of goods and services that are either locally produced or imported. The sources beyond the selected boundaries are also accounted for, except the exported goods. As the name implies, the emissions are allocated to the country or region of the final demand; and Scope 1 and Scope 2 emissions are accounted alongside the Scope 3 emissions embodied from import activities (Lombardi, Laiola, Tricase, & Rana, 2017) (OECD, 2016).

With the introduction of consumption-based perspective, awareness of the high emission amounts embodied in trade started to be developed (Larsen & Hertwich, 2010). Since consumption-based accounting considers all emissions related to the consumption of both locally produced and imported goods and services, it is deemed more comprehensive than the previous two perspectives. However, this perspective is not mentioned in international conventions; and more importantly, there are no standardized methods for the calculation of consumption-based emissions contrary to territorial and production-based calculations. Hence, different methods will result in different emission estimates. As another significant limitation to the use of this perspective, necessary statistical data on supply, consumption and trade are not often updated, which makes providing time-series of consumption-related emissions challenging (European Environment Agency, 2013).

The abovementioned three perspectives vary in terms of their coverage, scope, system boundaries (i.e. the type of information included), calculation methods; and the quality of data that they use. These differences affect the emissions calculations; and some results have an uncertainty ratio that represents the gaps in the data they are based upon. Accordingly, these uncertainties influence the extent to which the resulting data is applicable to policymaking.

According to the report prepared by the EEA in 2013, these three accounting perspectives are applied sequentially at the EU level. Territorial emissions are used as an input to production-based calculations and production emissions then form the basis of consumption-based calculations. Considering this sequence, the consumption-based perspective becomes particularly vulnerable to possible uncertainties. The uncertainty degree of the resulting consumption-based calculation not only depends on the availability of statistical data required by itself, but also on the quality of the territorial and production emissions data (i.e. the previous rings of the chain) (European Environment Agency, 2013).

4. Combined Production and Consumption Perspective

A combination of the production and consumption perspectives is also used in some cases. With this combined perspective, the emissions generated within the selected region are accounted as well as the indirect emissions originating from infrastructure (i.e. energy and water supply, wastewater infrastructure, air transportation, etc.) and non-infrastructure goods and services serving the community. Consequently, all the embodied emissions due to import and export activities are taken into account (Lombardi, Laiola, Tricase, & Rana, 2017).

Calculation Approaches

1. Bottom-up Approach

Bottom-up approach, by its simplest definition, refers to building up a complex system by gathering simple individual components. In other words, the outcome is achieved via interrelation of individual units. In CF calculation, bottom-up approach refers to the individual analysis of actual processes to investigate the GHG emission from each of them. This approach is used for CF calculation of processes, products and small entities; and is based on the Life Cycle Assessment (LCA) method. The term “life-cycle” denotes the sequential and interlinked stages of a products system, from raw material procurement or natural resources generation up until the end-of-life. LCA is the compilation and assessment of inputs, outputs and potential environmental effects of a product system through its life cycle (British Standard Institution, 2011).

LCA is mostly used for consumption-based accounting perspective as it is a means of accounting potential environmental impacts due to consumption of resources in each step of a product supply chain. LCA requires data to be collected for each process that has been deemed important within the defined system boundary. Hence, beside producing relatively more precise results, LCA can be highly data-demanding, time-consuming and laborious; and may lead to potential system boundary problems (Lombardi, Laiola, Tricase, & Rana, 2017).

Although LCA can be successfully used for CF calculation of specific case studies or processes, its application for municipal services and UCF calculation was found to be insufficient in a study conducted in Norway. The main reasons for this insufficiency were stated as the poor representativeness of services by LCA; and the complexity resulting from a substantial number of services purchased from other municipalities, the government or private entities (Larsen & Hertwich, 2010).

Consequently, LCA can be considered as an appropriate CF calculation tool with relatively higher accuracy level for smaller entities such as processes and products; however, it is likely to become unfavorable for CF calculation of larger entities such as municipalities, regions or countries since the complexity and insufficiency of the available data may increase as the system boundary is expanded.

2. Top-down Approach

Top-down approach, contrary to the “bottom-up”, aims to break a complex system into its simple individual components to provide a better understanding of its basics. It is used for CF calculations of large entities such as sectors, countries (national), regions and global studies. Top-down calculations are mainly conducted based on the “Environmentally Extended Input-Output Analysis (EE-IOA)” method.

Input-output analysis (IOA) is a macroeconomic tool that is useful for quantifying data on inter-industrial monetary transactions to elucidate the complex interdependencies of sectors and industries in modern economies. EE-IOA is an extended version of the economic input-output model with the integration of environmental impact indicators, such as carbon emissions or resource use, for each sector, region or nation. Fundamentally, production of all goods and services in an economy require direct and/or indirect energy use; and correspondingly lead to GHG emissions, based on the fuel type used. The EE-IOA is used to assess the associated carbon emissions of the aforesaid production activities embodied within international trades, i.e. import and/or export. Compared to LCA, EE-IOA is less time-consuming and laborious; however, it cannot be applied for micro systems (Lombardi, Laiola, Tricase, & Rana, 2017) (UNESCO, 2012).

Multi-Regional Input-Output Analysis (MRIOA) is an extended version of EE-IOA, which has been developed as another approach for the accounting of embodied trade emissions at multi-regional level, i.e. intranational, international or inter-city. Since the analyses are conducted at a multi-regional level with MRIOA, potential double counting of emissions that could happen with EE-IOA is avoided. Nevertheless, the use of MRIOA for emission trade balancing may not always be possible since it is based on specific data about the coordinated policy actions among cities connected through supply and demand chains; and such data are rarely found.

At the national level, EE-IOA is based only on national input-output tables, which constitute a monetary representation of the flow of goods and services among economic elements in a country. In line with the logic behind the top-down approach, carbon dioxide (CO_2) emissions related to a commodity/entity are not based on the actual processes or technologies as they are in the bottom-up approach; but rather on the processes stated in the input-output tables. Hence, the accuracy of results will be dependent upon the availability and quality of the input-output tables during CF analyses (Nansai, et al., 2009).

In Australia, since national input-output tables are compatible with national accounts data, tracking of GHG emissions from industry sources through the manufacturing system to final demand types has been possible. In the study conducted by Wood and Dey, Australia's national CF has been calculated by implementing the EE-IOA method through estimations of industry-based GHG emissions, including the emissions embodied in import, export and consumption categories. In the study, GHG emissions were assigned as exogenous inputs into each industry; and passed on from one industry to another throughout the production system, in line with the economic flows (Wood & Dey, 2009).

Japan is another country that establishes comprehensive input-output tables covering numerous sectors, and thus the IOA has been commonly used in the country, especially for LCA studies. However, for CF calculation purposes, only the bottom-up approach has been mentioned. In a study conducted in 2009, a CF quantification methodology that adopts IOA has been proposed since the IOA has not been specified in the national valid and provisional guidelines at that time. The study intended to benefit from the strengths of the IOA, such as its clear and extensive system boundary definition. Within this scope, the system boundary was extended from a single country to multiple countries and regions by using the Global Link Input-Output (GLIO) model. The GLIO model describes the relationship between the production and consumption systems of Japan and foreign countries through international trade; and it was used to demonstrate CO_2 emission intensities of certain commodities. As a result, commodities with relatively high foreign emissions were identified. Since the CF calculations require precise reflection of the features of individual commodities, the bottom-up approach should be applied for primary data collection; and this study claimed to facilitate the determination of which input data should rather be collected as primary data by the bottom-up approach (Nansai et al., 2009). It should be noted that the current guidelines in Japan still do not mention IOA but rather LCA for CF quantification (Japan Environmental Management Association for Industry, 2013).

Other such examples of national CF accounting studies conducted based on the EE-IOA approach include those of Brazil, China, United Kingdom and United States of America (UNESCO, 2012).

One benefit of adopting the EE-IOA method in national CF calculation is that it enables tracing both the direct and indirect results of exports and imports on a country's total GHG emissions (Machado, Schaeffer, & Worrell, 2001). On the other hand, since the EE-IOA method is mostly monetary and requires monetary and economic data, its implementation for CF calculations may be limited by potential data shortages arising from confidentiality concerns.

3. Hybrid Approach

With the areas of use, benefits and drawbacks of both the bottom-up and top-down approaches mentioned, comprehending the third approach, which is a combination of the two, becomes easier. Researchers recently proposed their combination methods with the intention of overcoming the drawbacks of the abovementioned approaches while utilizing their merged benefits. This approach is called as the "hybrid approach"; and it combines the specificity of LCA with the system completeness of EE-IOA, for products, organizations and nations. The level of detail and accuracy of the bottom-up approach are preserved; which is specifically useful for carbon-intensive sectors. First- and second-order process data are gathered for the product or service while higher order requirements are met by the IOA (Lombardi, Laiola, Tricase, & Rana, 2017) (UNESCO, 2012).

All in all, selection of the calculation approach to be adopted generally depends on the scale of the functional unit[6]. However, the general tendency shows that the top-down approach is used for emissions data gathering in large-scale studies, such as those at national level. On the other hand, the bottom-up approach (i.e. LCA) is applied in smaller scale CF calculation studies such as those of production process (Lombardi, Laiola, Tricase, & Rana, 2017).

[6] Functional unit is quantified performance of a product system to be used as reference unit. For GHG emission assessment purposes, it can be a single item of product or a generally recognized sales quantity (e.g. 1 egg or 1 dozen eggs) (British Standard Institution, 2011).

APPENDIX B

INTERNATIONAL EMISSION INVENTORY FRAMEWORKS

CF can be calculated at several levels and for a variety of entities, including processes, products, companies/businesses, industrial sectors, consumers (either as individuals or groups), and geographically delineated areas (UNESCO, 2012). Standardization efforts are ongoing for GHG accounting methods at most, if not all, of these levels. However, there are still too many alternative calculation standards and methodologies that have been formulated by different organizations, some of which will be detailed in this chapter. The foremost international frameworks at five main levels for CF accounting (i.e. product, project, corporate, urban and national-level) will be mentioned in this section, with the greatest emphasis placed on community/urban-level GHG inventory frameworks in line with the focus of this thesis.

Each emission inventory guideline has its own specific requirements and steps to be complied with. Still, the common flow of the steps taken to compose a GHG emissions inventory can roughly be listed as follows:

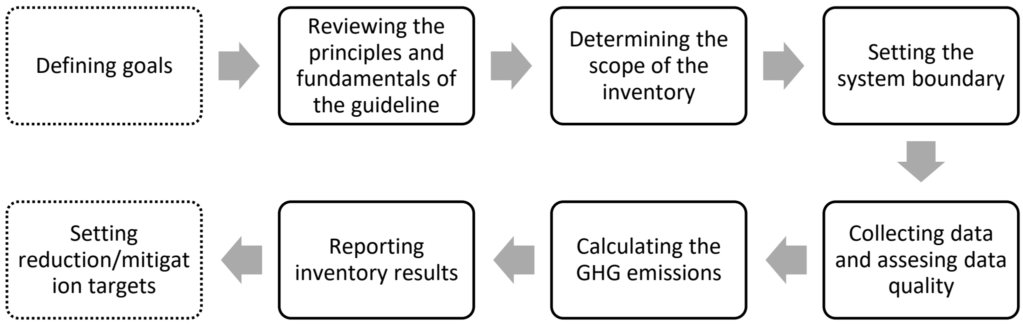


Figure B-1. Common Steps for Composing a GHG Emissions Inventory

The first step (i.e. defining goals) and the last step (i.e. setting reduction/mitigation targets) are optional and are performed depending on the objective of the inventory performer. However, they are crucial steps for policy-making purposes and particularly for climate change mitigation and adaptation policies and should not be omitted.

A) Product-Based CF Accounting

With the increasing awareness and concerns about climate change, CF of goods and services became an important issue. Investors started to demand increased transparency and consumers started to pay attention to environmental responsibility. Consequently, companies are requested to develop and disclose their corporate GHG inventories, which generally include the emissions from product supply chain (WRI and WBCSD, 2011). To be able to survive and achieve sustainable success in today's competitive business world, companies should be capable of comprehending and handling the risks related to their product-based GHG emissions.

Standardization of product level CF accounting has been under discussion and several institutions have published their own guidelines and standards within this scope (UNESCO, 2012). The most commonly adopted standards or specifications for product-based CF accounting are briefly introduced in this section.

A.1. Publicly Available Specification PAS 2050:2011: Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services by British Standard Institution (BSI)

Being one of the first standards that describe calculation methods for product CFs, *"Publicly Available Specification PAS 2050:2011: Specification for the assessment of the life cycle greenhouse gas emissions of goods and services"* (hereinafter referred to as "PAS 2050") was published in 2008 and updated in 2011. The update has been undertaken by BSI in line with the latest technical advances and experiences (British Standard Institution, 2011). It is mostly preferred by businesses to demonstrate their compliance with environmental standards to the consumers and stakeholders.

Content, Purpose and Applicability

PAS 2050 specifies the requirements and describes the calculation of GHG emissions of goods and services (collectively referred to as "products") based on the LCA approach. Product GHG emissions are those that are released as part of the processes of obtaining, creating, modifying, transporting, storing, using, providing, recycling or disposing of the products in question. The document covers and provides insight to the impacts of processes, materials and decisions occurring throughout the life cycle of products. It was developed to meet the high demand of community and industry for a consistent method of calculation and assessment of the life cycle GHG emissions of products; and offers organizations a technique to provide better understanding of the GHG emissions released from their supply chains.

PAS 2050 is stated to be commonly applicable to a broad range of products and to organizations assessing the life cycle GHG emissions of their products. However, with the recognition that the availability of certain supplementary requirements may support and/or facilitate consistent application of PAS 2050 to products within specific sectors, a set of principles governing the development and use of these supplementary requirements have been included in the updated PAS 2050:2011.

PAS 2050 builds on the existing LCA methodologies, principles and requirements of which have been established through two International Organization for Standardization (ISO) Standards, namely the *BS EN ISO 14040:2006, Life Cycle Assessment: Principles and Framework* (hereinafter referred to as "ISO 14040") and *BS EN ISO 14044:2006, Life Cycle Assessment: Requirements and Guidelines* (hereinafter referred to as "ISO 14044"), by further clarifying their implementation for the assessment of life cycle GHG emissions of products. ISO 14040 presents the principles and framework for LCA studies while ISO 14044 specifies the requirements for conducting an LCA.

Principles and Implementation

Unless otherwise stated, PAS 2050 requires the assessment of the GHG emissions of products to be executed by following LCA techniques, which are detailed in ISO 14040 and ISO 14044 standards. The techniques use the "attributional approach", which is an approach to LCA that assigns GHG emissions and removals to the functional unit of the assessed product based on its life cycle processes (British Standard Institution, 2011) (WRI and WBCSD, 2011). In cases where the approach described in the aforementioned standards conflicts the requirements of PAS 2050, the requirements of PAS 2050 predominate.

The main principles that organizations should follow while conducting their assessment through PAS 2050 are listed as *relevance, completeness, consistency, accuracy* and *transparency*; and can be briefly explained as follows:

- ***Relevance:*** refers to the selection of appropriate emissions/removals data and assessment methods which are relevant to the studied product,
- ***Completeness:*** requires all life cycle emissions and removals of the studied product that occur within the selected system boundaries to be included in the inventory,
- ***Consistency:*** requires the assumptions, methods and data to be applied in the same way throughout the study, and to support reproducible and comparable results,
- ***Accuracy:*** requires the bias and uncertainty to be reduced as far as possible and practical,
- ***Transparency:*** where the emissions assessment results are to be disclosed to a third party, *transparency* requires the emissions-related information to be made available and allow the third party to make related decisions with confidence.

Within the scope of PAS 2050, the quantification of life cycle GHG emissions and removals of products are classified as either:

a) “cradle-to-grave”, if it covers the GHG emissions and removals that result from the full life cycle of the product; or
b) “cradle-to-gate”, if it comprises the emissions and removals up to and including the point at which the product leaves the organization conducting the assessment, to be transferred to another party that is not the consumer.

Scope of the Inventory

PAS 2050 requires both the emissions to the atmosphere and removals from the atmosphere to be measured and accounted by their mass and to be converted into CO_2 equivalent (CO_2e), using the latest 100-year GWP coefficients produced by the IPCC. The GHGs to be covered in the calculations are comprised of a long list of gases resulting from both fossil and biogenic[7] sources for all products excluding human food and animal feed products. The full list of GHGs to be covered are presented as an Annex of PAS 2050, together with their GWPs. Major components of the list include the following:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- Chlorofluorocarbons (CFCs)
- Hydrochlorofluorocarbons (HCFCs)
- hydrofluorocarbons (HFCs)
- perfluorocarbons (PFCs)

Carbon storage may occur in products where some or all of the removed carbon will not be emitted to the atmosphere within the 100-year assessment period. Carbon storage might occur where biogenic carbon constitutes a portion of a product or its whole, where carbon within the product’s composition is not released to the atmosphere in the form of CO_2 or CH_4 during waste treatment through combustion/decomposition, or if atmospheric carbon is taken up by a product over its life cycle. An example to carbon storage would be that in a chair made up of wood fiber. In case any carbon storage is included in the life cycle emissions

[7] Derived from biomass, but not from fossilized/fossil sources (British Standard Institution, 2011)

assessment of a product, the data sources from which the quantity of stored carbon was calculated, and the 100-year carbon storage profile of the product should be recorded and retained as per PAS 2050 requirements.

System Boundary

Emissions assessment is conducted to determine the mass of CO_2e per functional unit for products; and to determine the mass of CO_2e based on time or event for services (e.g. annual emission arising from an internet service). PAS 2050 assessment of products' life cycle GHG emission and removal covers the 100-year period following the formation of the product. If significant emissions are expected to occur beyond this 100-year assessment period for specific products or sectors, supplementary requirements should ensure the involvement of these emissions.

Product life cycle processes to be included in the emission calculations include, but are not limited to *energy use, combustion processes, chemical reactions, loss to atmosphere of refrigerants and other fugitive GHGs, service provision and delivery, land use and land use change, livestock production and other agricultural processes;* and *waste management*.

PAS 2050 requires the system boundary to be clearly defined for each product and to include all material life cycle processes, except those defined under system boundary exclusions. Clear identification of the likely GHG removal stages within the product life cycle while establishing the system boundary is crucial to facilitate gathering of removal data in the inventory process. Also, cradle-to-gate assessment information should be clearly specified in order not to be confused with a full assessment of the life cycle GHG emissions of a product.

Product systems consist of interconnected life cycle stages, with processes or emissions/removals assigned to each of them. Product life cycle processes are represented under these life cycle stages, which can typically be listed as *raw materials; manufacture; distribution/retail; use;* and *final disposal/recycling.* In case of services, depicting life cycle stages can be more difficult since not all stages may be relevant. For instance, *raw materials*, *production* and *use* stages of goods can be merged into the *service delivery* stage for services.

Although may vary depending on the product, the life-cycle elements, GHG emissions and removals of which are included in the system boundary for the assessment, can be listed as follows:

- *Production Materials* – all processes used in the formation, extraction or transformation of materials used in production, including all sources of energy consumption or direct GHG emissions associated with that formation, extraction or transformation.
- *Energy* – provision and consumption of energy in the product life cycle. It should be noted that emissions from energy cover the emissions from the life cycle of the energy itself, including those:
    - at the point of consumption of the energy,
    - resulting from the provision of the energy,
    - from transmission losses, transport fuels, upstream and downstream emissions[8]; and
    - from growing and processing of biomass to be used as a fuel.
- *Manufacturing and Service Provision* – manufacturing and service provision stages of the product life cycle, including the use of consumables.
- *Operation of premises* – operation of premises such as offices, factories, warehouses, etc.
- *Transport* – road, air, water, rail and other transportation means that constitute a portion of the product life cycle.
- *Storage* – storage of inputs, including raw materials, at any phase of the product life cycle; environmental controls related to a product such as

[8] Upstream emissions are GHG emissions associated with processes that occur in the product life cycle prior to the processes owned, operated or controlled by the organization implementing PAS 2050; while downstream emissions are those arising from processes that occur subsequent to the organization's processes (British Standard Institution, 2011).

cooling or heating; product storage in the use phase and prior to reuse, recycling or disposal.

- *Use* – the use of products is included in the assessment, unless it is specified as a “cradle-to-gate assessment”. Calculations for energy use are done based on country-specific annual average emission factors for energy.
- *Final disposal* – waste disposal through landfilling, incineration, burial and wastewater, unless it is specified as a “cradle-to-gate assessment”. Subject to the specific provisions stated for emissions from waste.
- *Capital goods* – emissions and removals originating from the production of capital goods used in the product life cycle shall be excluded unless the supplementary requirements state otherwise.

Determination of the use profile (for the use phase) and waste disposal profile (for the final disposal phase) are based upon the hierarchy of boundary definitions, which specify a use/waste disposal profile of the product being assessed, in the following order of preference:

1) Supplementary requirements
2) Published international standards
3) Published national guidelines
4) Published industry guidelines.

PAS 2050 system boundary excludes the emissions associated with:

a) human energy inputs to processes and/or pre-processing (such as manual picking of fruits rather than mechanical),
b) consumers’ transportation to and from the retail purchase point,
c) employees’ transportation to and from their normal work place; and
d) animals providing transport services

from the product life cycle.

Data

The recorded data should include all GHG emissions and removals occurring within the defined system boundary; and should follow the specified data quality rules of

PAS 2050. In general terms, data quality rules underline *time-specificity, geographical and technological specificity, accuracy;* and *precision* of data.

Primary activity data should be collected from the processes owned, operated or controlled by the organization. Downstream emission sources are out of the scope of this requirement while obtaining primary data for upstream emissions enables the organization to differentiate the GHG assessment of its products from other products. Measurement of energy or material use in a process or fuel use in transport can be given as examples to primary activity data. Reflection of the conditions normally encountered in the product-specific processes is important for the primary data to be representative. In cases where primary data have not been obtained, secondary data should be used. Secondary data supplied from competent sources such as national government, official United Nations (UN) publications and publications by UN-supported organizations; and peer review publications should be favored rather than other resources.

In cases where an input to a process results from multiple sources; emissions and removals data are collected from a representative sample of the sources used in the assessment. The use of sampling should meet the previously mentioned data quality requirements. Also, results from the implementation of PAS 2050 should be valid for maximum two years, unless there is a change in the product life cycle, in which case the validity discontinues.

PAS 2050 may require an allocation of emissions and removals in cases of co-product presence, emissions resulting from waste, use of recycled material and recycling; and emissions from reuse, transport or energy production using Combined Heat and Power (CHP)[9].

Calculation

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[9] CHP is on-site electricity generation that captures the heat that would otherwise be wasted to provide useful thermal energy—such as steam or hot water—that can be used for space heating, cooling, domestic hot water and industrial processes. CHP can achieve efficiencies of over 80%, compared to 50% for conventional technologies (i.e., grid-supplied electricity and an on-site boiler) (EPA, 2016)

PAS 2050 involves the accounting of both emissions to the atmosphere and removals from the atmosphere during the product life cycle. The below methodology is applied for the calculation of life cycle GHG emissions per functional unit of the product under evaluation:

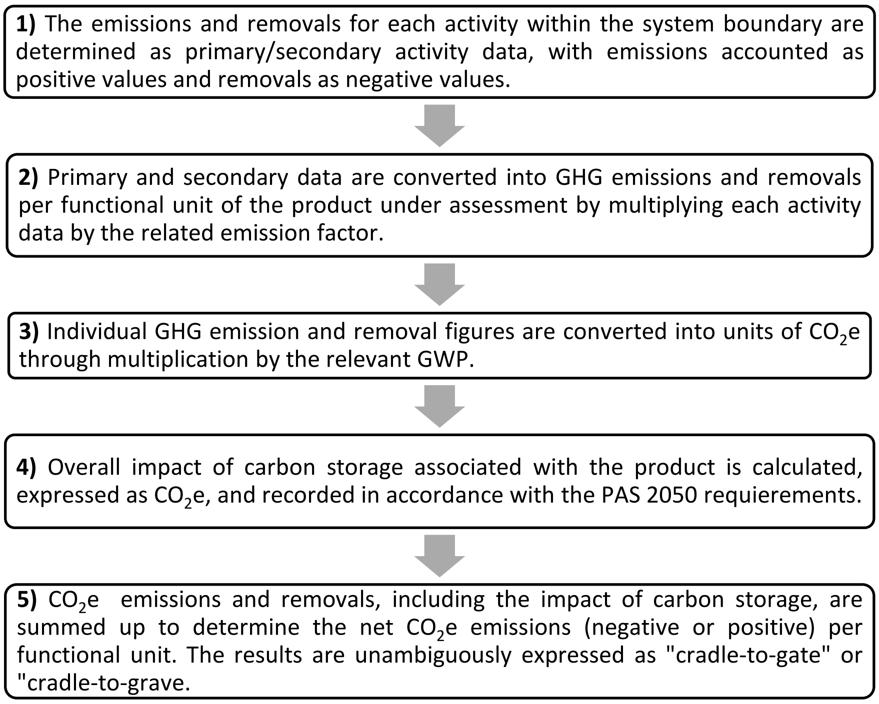


Figure B-2. PAS 2050 Methodology for life cycle GHG emissions calculation

A.2. GHG Protocol - "Product Life Cycle Accounting and Reporting Standard (2011)" by WRI and WBCSD

The GHG Protocol – Product Life Cycle Accounting and Reporting Standard (hereinafter referred to as the "Product Standard") was established in 2011 by the GHG Protocol, which is a multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), and others convened by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). Since 1998, the GHG Protocol has been aiming to develop internationally accepted GHG accounting and reporting standards; and to promote their implementation. To do so, the partnership has produced several standards, protocols and guidelines, each of which are complementary. The published standards cover the quantification of corporate emissions, value chain (Scope 3) emissions, community-scale emissions and emissions from public sector organizations as well as the emission reductions due to GHG mitigation projects. During the development of these standards, a balanced contribution is received from governmental agencies, NGOs, businesses, industries and academic institutions.

Content, Purpose and Applicability

As per the measures taken against the impacts of climate change, companies started to focus not only on the emissions from their own operations; but also on those resulting from their value chains (i.e., the processes by which a company adds value to a product, including the design, production, marketing, purchase or use). The Product Standard is one of the best-known standards published by the GHG Protocol, and it primarily aims to provide companies a general framework to account for and publicly report the product-based GHG emissions and removals along their value chain, and to comprehensively manage the related risks and opportunities through informed decision-making. It is also deemed useful for tracking the performance of a product's GHG inventory and emissions reductions.

The Standard was established to meet the demand for an internationally accepted method for preparing a GHG emission inventory of companies' products. It was intended to be more than a technical accounting tool and to be tailored to real-life conditions; therefore, a stakeholder feedback mechanism was established to continuously improve the practicality and applicability of the standard and the quality of the GHG inventories. It has a wide range of applicability as it was designed to be used by companies and organizations of any size from any economic sector in any country. It can also be adopted by interested policy makers to be integrated into their policies and programs.

The Product Standard is closely related to two other GHG Protocol Standards, namely *"The GHG Protocol Scope 3 Standard"* (i.e. the Scope 3 Standard) and *"The GHG Protocol Corporate Standard*" (i.e. the Corporate Standard). The Scope 3 Standard builds on the Corporate Standard and takes account of the value chain

GHG emissions at the corporate level while the Product Standard does the same at the individual product level. Together, these three standards deliver a comprehensive approach for the accounting and management of value chain emissions. The choice of which specific standard or combination of standards to use depends upon the business goals of the reporting company. In the most general sense, The Scope 3 Standard is supportive for companies to identify GHG reduction opportunities and track their performance at corporate level; while the Product Standard serves for the same objectives at a product level.

Principles and Implementation

The Product Standard builds on the life cycle assessment context established by the ISO LCA Standards (i.e. ISO 14040 and ISO 14044) and PAS 2050, in an attempt to deliver further guidance to enable reliable quantification and reporting of product GHG inventories. Hence, GHG emissions accounting of products shall be based on the life cycle and attributional approaches within the scope of the Product Standard.

The principles to be followed while conducting emissions accounting and reporting under the Product Standard are the same as those of PAS 2050, which are *relevance, completeness, consistency, transparency and accuracy*. As per the Standard, companies should first set business goals before establishing their product GHG inventories to bring further clarity and to facilitate the selection of the appropriate methodology and data. The Product Standard states the business goals served by a product GHG inventory as climate change management, performance tracking, supplier and customer stewardship, and product differentiation.

Scope of the Inventory

In addition to determination of the GHGs to be accounted for, the Product Standard requires choosing and defining the studied product, the unit of analysis and the reference flow. Unit of analysis is defined as the performance characteristics and services delivered by the studied product. For the final products[10] where the

[10] Final products are goods and services that are eventually consumed by the end-user rather than used in the production of other goods and services (WRI and WBCSD, 2011).

function is known, companies shall define the unit of analysis as a “functional unit”. On the other hand, the unit of analysis shall be defined as the “reference flow” for intermediate products[11] where the eventual function may not be known since it is dependent on the function of the final product it becomes. Reference flow is defined as the amount of selected product needed to execute the function defined in the unit of analysis.

Companies should account for the emissions to and removals of the below GHGs, if they are emitted during the product’s life cycle, to conform with the Product Standard:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- Sulphur hexafluoride (SF_6)
- perfluorocarbons (PFCs)
- hydrofluorocarbons (HFCs)

If any additional GHGs, whose 100-year GWP values are identified by the IPCC, are emitted and are also to be accounted for, they should also be stated in the report in line with the *transparency* principle. CO_2 removals may occur when a product absorbs atmospheric CO_2 during use or if CO_2 is used during a processing stage. Such CO_2 removals, what is called as “carbon storage” in PAS 2050, should also be included in the inventory by the companies.

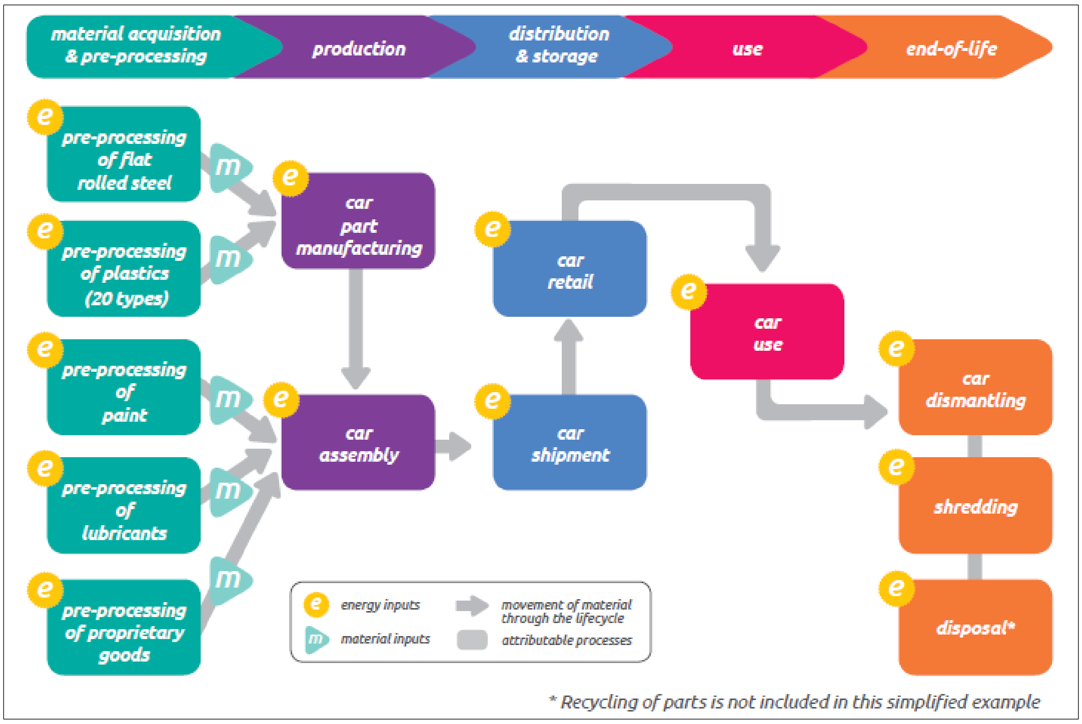
System Boundary

The Product Standard requires the inventory to include all attributable processes along with the definitions and descriptions of each stage. Examples to attributable process include the product’s components and packaging, manufacturing, materials used to enhance its quality (e.g. fertilizers), and the energy used to move, produce or store the product. Attributable processes may be excluded from the inventory under certain circumstances; however, the companies should disclose and justify

[11] Intermediate products are goods that are used as inputs in the production of another good or service, to eventually become a final product (WRI and WBCSD, 2011).

this exclusion in the report. Insignificant data, data gaps due to problems in primary/secondary data collection and incapability to fill the data gaps are the main reasons for the exclusion of attributable processes.

The attributable processes shall then be grouped into life cycle stages, in order to be included in the emission/removal calculations. Five general life cycle stages are specified by the Standard, which are *nature, material acquisition & pre-processing, production, distribution & storage, use,* and *end-of-life*. These stages may be elaborated or changed by companies to better reflect a particular product's life cycle. The system boundary for final products should be set based on cradle-to-grave removals and emissions (i.e. from *material acquisition* to *end-of-life*). The system boundary for intermediate products is set as "cradle-to-gate" boundary if the function of their final product is unknown, and as "cradle-to-grave" boundary if it is known. After the grouping of attributable processes into life cycle stages, identification of the service, material and energy flow needs for each process should be made, and all the life cycle processes should be illustrated through a process map. A sample process map developed for a car is presented in Figure B-3 below, which is based on cradle-to-grave inventory. As can be seen, the attributable processes are grouped under relevant life cycle stages; and all the energy and material flows are clearly demonstrated. A properly developed process map is crucial for an inventory since processes and flows demonstrated in the map are the basis for data collection and calculation. Hence, the Standard provides a detailed and step-by-step guidance to companies on developing a process map.



Source: (WRI and WBCSD, 2011)

Figure B-3. A sample process map developed for a car

As per the Standard, time period of the inventory shall be based on the total time the considered product completes its life cycle by starting from its materials' extraction from nature up to the point they are returned to the nature at the end-of-life (e.g. landfilled or incinerated) or leave the life cycle (e.g. recycled). Non-durable goods such as perishable foods or fuels have a time period of one year or less, while durable goods such as cars or computers have a time period of three years or more. It should be noted that the time period should be based on scientific evidence; and if known science, sector guidance or product rules do not exist for a particular product, companies should assume a minimum time period of 100 years, including the *end-of-life* stage. The Product Standard also provides guidance on whether land use change impacts are attributable to the product in question or not; and presents methods for its calculation.

Data

Data for all processes included in the system boundary should be collected as per the Product Standard. Within this scope, The Product Standard provides a step-by-step and detailed guidance for successful data collection as well as for assessing the quality of their data and inventory, which is summarized in seven steps:

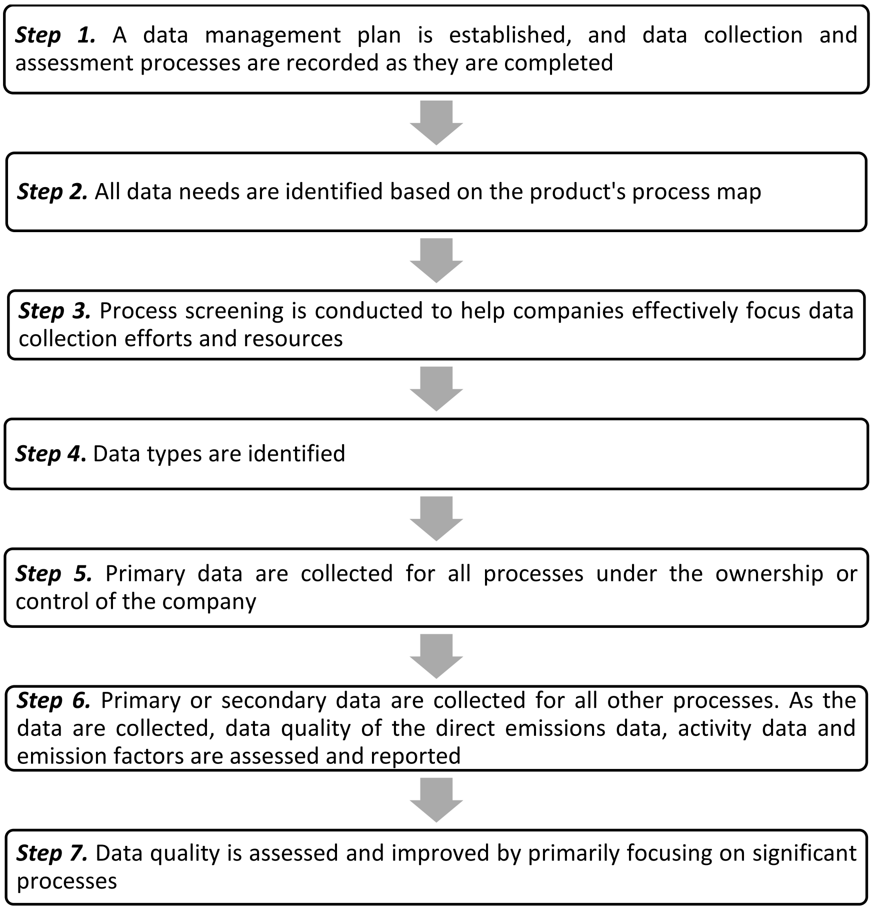


Figure B-4. Guidance for successful data collection and quality assessment

According to the Standard, a data management plan is a tool to organize and consistently document the data collection process, including the data sources, assumptions and data quality (WRI and WBCSD, 2011). The plan is suggested to be developed early in the inventory process to ensure that all the relevant information is recorded. After the data needs are identified based on the process map or the data management plan, screening of the processes based on their appraised contribution to the total life cycle is suggested; yet it is not mandatory. It is stated in the Standard that such screening can help companies prioritize their data collection efforts and resources more efficiently. As the subsequent step, identifying data types is important as it will provide a better understanding of data and their quality. Typically, data can be gathered either by directly measuring or modeling the emissions from a process, or by collecting activity data and emission factors for the process and multiplying the two to achieve GHG emissions. Either way, the source of data should be documented in the data management plan. Activity data are divided into two categories as "process activity data" and "financial activity data". On the other hand, emission factor sources may include life cycle databases, published product inventory reports, government agencies, peer reviewed literature, and more.

As per the Standard, reporting companies shall collect primary data for all studied processes under their ownership or control, as long as they are available and of sufficient quality. The Standard defines primary data as data from specific processes related to the studied product. Process activity data, direct emissions data[12] from a specific site, or data that is averaged across all sites involving the specific process, are all regarded as primary data by the Standard. Measured or modeled primary data are acceptable provided that the result is specific to the considered process. Secondary data, on the other hand, is defined as data that are not from specific processes related to the studied product. With this respect, direct emission data and process activity data that do not match the definition of primary data can be classified as secondary; and financial activity data are always classified as secondary.

As the final step, assessing data quality is important during data collection as it helps companies determine which data better represents the actual emissions released, among several options. The Product Standard identifies five data quality indicators for assessing the quality of activity data, emission factors, and/or direct emissions data during the data collection process. The quality indicators are namely

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[12] Direct emissions data are data on emissions released from/removed by a process and determined through methods such as direct monitoring, stoichiometry or mass balance (WRI and WBCSD, 2011)

technological representativeness, geographical representativeness, temporal representativeness, completeness and *reliability*. Depending on the results of data quality assessments, data quality improvement may be required, especially for significant processes that have a substantial amount of GHG emission contribution to the inventory. In other words, if data sources are scored as "low quality" based on the data quality indicators, data should be re-collected for the problematic processes (by prioritizing significant processes) as many times as necessary and as resources allow. More efficient data quality improvement can be achieved by assessing the data quality during data collection rather than after the collection is completed.

Data gaps occur when there is no primary or secondary data that is adequately representative of the process. The Product Standard suggests using proxy data, which are data from similar processes that can be used as backup, for filling such data gaps. Proxy data can be customized, extrapolated or scaled up to better represent the process metrics in question. If proxy data cannot be collected to fill a data gap, companies shall estimate the data to determine the significance of the process. If a process is deemed insignificant, it can be excluded from the inventory. Further guidance on determining insignificance is provided in the Standard.

Allocation and Uncertainty Assessment

Prior to calculating the inventory results, The Product Standard requires allocating the emissions and removals (briefly referred to as "allocation"); and assessing uncertainty. Allocation is a process that is required in case of the presence of common processes with multiple valuable products as inputs or outputs, and for which it is not possible to collect data at the individual input or output level (WRI and WBCSD, 2011). Allocation, by meaning, refers to the partitioning of total emissions or removals among these multiple inputs and outputs to address common processes; and accurate allocation is a crucial tool for maintaining the quality of an inventory. According to the Standard, common processes produce two kinds of products, namely the studied products or the co-product(s) that become an input into another product's life cycle. Services, materials or energy inputs can be inputs to the common process while intermediate/final products, energy outputs or waste can be listed as their typical outputs. The Product Standard primarily suggests avoiding allocation wherever possible and if it is inevitable, requires performing allocation based on an appropriate approximation or method. Accordingly, detailed guidance on when and how to avoid or perform allocation is provided to companies with examples.

As per the Standard, companies shall report a qualitative assessment of inventory uncertainty and its sources along with the methodological choices throughout inventory development. Identifying and reporting the sources of uncertainty is also stated to help companies understand the requirements to improve the quality of the inventory and increase its reliability. While qualitative descriptions are emphasized under reporting requirements, quantitative uncertainty assessment is deemed desirable as it may help companies prioritize their data quality improvement efforts on specific sources that have the highest contribution to overall uncertainty. The Product Standard examines uncertainty under three categories, namely “parameter uncertainty”, “scenario uncertainty” and “model uncertainty” and provides guidance on how to report them with examples. In this scope, direct emissions data, activity data, emission factors and GWP factors are listed as the potential sources of parameter uncertainty while methodological may lead to scenario uncertainties and model limitations may cause model uncertainties.

Calculation

As per the Product Standard, companies shall calculate and report the overall inventory results in CO_2e by applying 100-year GWP factors from the latest IPCC Assessment Report to emissions and removals. It should be noted that as of early 2018, the latest Assessment Report is the Fifth Assessment Report (AR5) that was released between September 2013 and November 2014, and the IPCC is currently in its Sixth Assessment Cycle (IPCC, 2017).

Offsets and avoided emissions[13] are both categorized as actions that occur outside the boundary of the product's life-cycle; and they shall both be excluded from the inventory results along with the weighting factors for delayed emissions[14]. They can be separately reported, if desired. On the other hand, the amount of carbon stored by the product shall be reported, if applicable. The Product Standard requires the following steps to be taken during quantification of the emissions of the studied product:

Step 1. A GWP value is chosen, and its source is disclosed.

Step 2. CO_2e is calculated by using the data collected

i. If the collected data is process of financial activity data, the basic equation below is used to calculate the CO_2e for an input, output or process:

$$kgCO_2e = ActivityData(unit)\ x\ EmissionFactor[kgGHG/unit]\ x\ GWP[kgCO_2e/kgGHG]$$

ii. If the collected data is direct emissions data, the need for emission factor is eliminated and the equation becomes:

$$kg\ CO_2e = Direct\ Emissions\ Data\ (kg\ GHG)\ x\ GWP\ [kgCO_2e/kgGHG]$$

iii. If both the activity data and the direct emissions data are available, calculation may be done both ways to double-check.

iv. Biogenic uptake during photosynthesis is the most commonly encountered form of atmospheric CO_2 removal. In such cases, the amount of biogenic

[13] Offsets are the emission credits (in the form of emission trading or funding of emission reduction projects) purchased by a company to compensate the emissions caused by the studied product. Avoided emissions refer to emission reductions that are indirectly caused by the studied product of a process in its life cycle

[14] In some life cycles, especially those of products with long use and end-of-life time periods, emissions may occur at different times and therefore may have varying effects on the atmosphere. A weighting factor is applied to demonstrate the emissions delayed over time, which is also called "emission discounting" (WRI and WBCSD, 2011).

carbon contained in the product is generally known and to convert this amount into CO_2, it is multiplied by the ratio of molecular weights of CO_2 and carbon, respectively (i.e. 44/12). CO_2 removal calculation does not require an emission factor and the below equation is used:

$$kg\ CO_2e = kg\ Biogenic\ Carbon\ x\ \left({}^{44}/_{12}\right)\ x\ GWP\ [kgCO_2e/kgGHG]$$

Step 3. Total inventory results are calculated as CO_2e/unit of analysis

Companies shall ensure that all of the calculated results in CO_2e are on the same reference flow basis. That is to say, if the reference flow for the selected product is 100 kg and the inventory results are calculated per kg, the results shall be multiplied by 100. Then, results on the reference flow basis are summed together to achieve the result as "total CO_2e/unit of analysis". Total inventory results are comprised of the following elements, unless no land-use change impacts are attributable, or no removals occur during the product life cycle:

$$\frac{Total\ CO_2e}{unit\ of\ analysis} = \frac{CO_2e\ Emissions\ (Biogenic)}{reference\ flow} - \frac{CO_2e\ Removals\ (Biogenic)}{reference\ flow} + \frac{CO_2e\ Emissions\ (Non\text{-}Biogenic)}{reference\ flow} - \frac{CO_2e\ Removals\ (Non\text{-}Biogenic)}{reference\ flow} + \frac{CO_2e\ Land\ Use\ Change}{reference\ flow}$$

Step 4. Percentage inventory results are calculated by life cycle stages

Step 5. If applicable, biogenic and non-biogenic emissions and removals[15]; and land-use change impacts are reported separately for the sake of transparency.

Step 6. Cradle-to-gate and gate-to-gate[16] inventory results are calculated and reported separately unless confidentiality is a concern, as gate-to-gate inventory

[15] Biogenic emissions include CO_2, CH_4, and N_2O, which are released as a result of combustion and/or degradation of biogenic materials, wastewater treatment, and from certain biological sources in soil and water. Non-biogenic emissions cover all GHG emissions from non-biogenic (e.g., fossil-based) materials. Biogenic removals refer to CO_2 uptake by biogenic materials during photosynthesis, while non-biogenic removals only occur if CO_2 is removed from the atmosphere by a non-biogenic product during its production or use (WRI and WBCSD, 2011).

might risk the company confidentiality. Separate calculation and reporting provides the reporting company with further insight into which emissions and removals occur under their control. Although this process might be time-consuming, it can significantly contribute to internal emission reduction measures of the reporting companies by providing valuable input.

Additional Steps

After completing the emissions inventory, The Product Standard requires obtaining assurance over the inventory by a first or third party. Assurance refers to the level of confidence that the inventory and report are complete, accurate, consistent, transparent, relevant and without material misstatements (WRI and WBCSD, 2011). First party assurance is when the reporting company itself also performs the assurance process, while third party assurance is when a party other than the reporting company performs it. It should be noted that third party assurance is likely to increase the reliability of the inventory for external stakeholders. Nevertheless, greater stakeholder trust in the inventory and the reported information can be achieved through assurance, regardless of its being conducted by a first or third party. Specifications and guidance on the assurance process is provided in the Standard with detailed explanations.

Despite not being mandatory, setting a reduction target, identifying reduction opportunities and tracking inventory changes are strongly encouraged by the Product Standard since its ultimate goal is to help companies improve the quality and consistency of their inventories; and reduce product emissions. Accordingly, a step-by-step guidance is provided in the Standard for setting targets and tracking performance.

[16] Gate-to-gate inventory covers the emissions and removals occur while the studied product is under the ownership or control of the reporting company.

A.3. ISO/TS 14067:2013 Greenhouse Gases - Carbon footprint of products – Requirements and Guidelines for quantification and communication

The ISO/TS 14067:2013 Greenhouse Gases - Carbon footprint of products - Requirements and Guidelines for quantification and communication (hereinafter referred to as "ISO/TS 14067") is a standard under development, and therefore is classified as a "TS (Technical Specification)". It specifies the principles, requirements and guidelines for the quantification and communication of the CF of products; based on the ISO LCA Standards (i.e. ISO 14040 and ISO 14044) for quantification, and ISO standards on environmental labels and declarations (ISO 14020, ISO 14024 and ISO 14025) for communication. It also presents additional requirements for when the CF information is planned to be publicly accessible. Offsetting is not within the scope of this TS. The beneficiaries of this TS include organizations, governments, communities and other interested parties (ISO, 2013). Among the main objectives of ISO/TS 14067 are to increase transparency in product life cycle emissions quantification and reporting; and to ensure that CF data will be comparable worldwide (ISO, 2012).

B) Project-Based (Assessment of Project GHG Emissions) CF Accounting

As a global response to drastically increasing GHG concentrations in the atmosphere and the resulting effects of climate change, climate change mitigation-oriented projects (GHG projects) and investments emerged. The number of GHG projects increased especially with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), entering into force in 2005 and setting solid and internationally binding emission reduction targets. These targets were defined as "quantified emission limitation and reduction commitments" (also known as QUELROs), and entailed certain policies and measures including renewable energy investments, energy efficiency applications, protection of carbon sinks, sustainable agriculture activities, research and development (R&D) on innovative environmental technologies, and many more (Hedger, 2013).

To achieve these targets and encourage the associated actions, numerous financing mechanisms and funds have been established by the UNFCCC, the Kyoto Protocol, and international financial institutions (IFIs). Market-based carbon financing mechanisms were operationalized under the Kyoto Protocol, which offered country Parties an additional means of meeting reduction targets on top of their national measures (UNFCCC, 2014). The Kyoto mechanisms are namely the "Clean Development Mechanism (CDM)", "International Emission Trading System (ETS)" and the "Joint Implementation (JI)" mechanisms. Apart from the Kyoto mechanisms, the UNFCCC formed a Financial Mechanism to deliver funds to developing country Parties, operation of which is assigned to the Global Environment Facility (GEF) and the Green Climate Fund (GCF) (UNFCCC, 2014). In addition, IFIs provide financial support through climate-related funds, such as the Climate Investment Funds (CIF) of the World Bank. Finally, voluntary GHG programs and carbon certification bodies such as the Verified Carbon Standard (VCS) and the Gold Standard were founded by environmental and business leaders and NGOs to ensure that the GHG projects in the voluntary carbon market provide emission reductions and foster sustainable development (Gold Standard, 2018) (VCS, 2017).

In the light of the above information, it can be stated that project-based CF accounting mostly refers to quantification of GHG emission reductions or removal enhancements intended to be achieved by a GHG project or activity, in line with the climate change mitigation policies and low carbon development efforts. Almost each financing and certification mechanism has developed and published its own methodology for project-based CF accounting to interpret, measure and assess the emissions-related impacts of projects. It should be noted that there is an effort for harmonization of methodologies among the IFIs. In 2012, foundation of a harmonized approach to project-based GHG accounting was laid by the "International Financial Institution Framework for a Harmonized Approach to Greenhouse Gas Accounting"; the purpose of which is to establish minimum requirements in undertaking this work as well as to improve uniformity and comparability across IFIs (The World Bank, 2015). As of November 2015, participating IFIs finalized harmonizing their methodologies for renewable energy, energy efficiency, and transportation projects (GEF, 2018). Although the harmonization framework is a significant step towards forming standard methodologies, there is more work to be done.

Examples to the standards or methodologies for the emissions accounting and reporting of GHG projects published to date include but are not limited to:

- *"The GHG Protocol for Project Accounting" (2005),*
- *"ISO 14064-2:2006 - Greenhouse gases — Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements" (2006),*
- *"EBRD Methodology for Assessment of Greenhouse Gas Emissions" (2010),*
- *"European Investment Bank (EIB) Methodologies for the Assessment of Project GHG Emissions and Emission Variations" (2014),*
- *"Guidelines for Greenhouse Gas Emissions Accounting and Reporting for GEF Projects" (2015),*
- *World Bank GHG Accounting Guidance Notes for projects or investments of different sectors (2013-2014),*
- *"IFC Greenhouse Gas Reduction Accounting Guidance for Climate-Related Projects" (2017),*
- *Verified Carbon Standard (VCS) guidance documents and methodologies for projects or investments of different sectors,*
- *approved baseline and monitoring methodologies for large scale CDM project activities, which include 91 large scale methodologies and 25 consolidated methodologies at the time of the writing of this thesis* (CDM, 2018).

Since there are many methodologies by several entities, and since project-based CF accounting is not directly related with the objective of this thesis, details of the relevant methodologies will not be discussed.

C) Corporate-Level CF Accounting

Corporate-level emissions accounting is performed by a wide range of entities, including companies, businesses, NGOs, universities, governments and government agencies; who aim to find out the impact of their corporate emissions (i.e. the emissions generated due to their activities) and potential mitigation opportunities. For the sake of terminological simplicity, the terms "company" or "business" will be used in short for the said organizations, in concordance with the *"GHG Protocol: A Corporate Accounting and Reporting Standard"* (hereinafter referred to as "the Corporate Standard") by WBCSD and WRI (WBCSD and WRI, 2004).

Ever since GHG accounting has emerged as a supportive tool for monitoring climate change mitigation policies and strategies, corporate-level GHG accounting has become an important part of it. The number of companies that assess their GHG emissions level and the associated threats and opportunities has been continuously increasing in line with the climate change policies. Most governments attempt to reduce their emissions through national policies (i.e. emissions trading programs, voluntary GHG programs, taxes, regulations and standards); therefore, companies must be able to comprehend and tackle their emission-related impacts and risks to survive in a competitive corporate environment and ensure lasting success (WBCSD and WRI, 2004). Beyond creating business value, corporate GHG inventories adds prestige to companies; and even more, they become part of the overall business strategy of some. It should also be noted that there is a growing demand from governments, investors and other stakeholders for corporate transparency in terms of environmental information. This increasing demand is also reflected in the *"OECD Guidelines for Multinational Enterprises"*, which encourages companies to develop emission reduction strategies and reveal their climate change-related information (Kauffmann, Less, & Teichmann, 2012).

Mandatory and voluntary government schemes, which were established in the late 1990s, have also been growing in number. These schemes require or encourage companies to quantify and report their GHG emissions; and as they increased in number, the number of reporting companies has also increased. According to OECD, in the past 20 years, several OECD countries including Australia, Canada, France, Israel, Japan, New Zealand, the UK and the US, established government schemes (Kauffmann, Less, & Teichmann, 2012). With the implementation of these schemes, standard quantification methodologies emerged and became the methodologies of reference today, even though some countries use their own methodologies, or some important differences remain. The said reference methodologies are namely "*the Corporate Standard*" and "*ISO 14064:2006 – Greenhouse Gases – Part 1: Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals*" (hereinafter referred to as "ISO 14064").

In Turkey, the *"Regulation on Monitoring GHG Emissions"*[17] is followed for monitoring the facility-level GHG emissions from sectors such as electricity and steam production, cement, steel, ceramics, paper and glass, which account for about half of Turkey's total GHG emissions. With the amendment made in the Regulation on May 31, 2017; companies that perform certain activities and/or have a certain production capacity have been obliged to report their GHG emissions to the Ministry of Environment and Urbanization (MoEU). While this relatively recent improvement is considered an important monitoring tool, its effective enforcement is of greater importance and should be ensured. If effectively managed, the Regulation can provide the basis for more comprehensive government schemes in the future.

Since corporate-level GHG accounting is not directly related with the objective of this thesis, details of the relevant methodologies will not be discussed.

[17] Regulation on Monitoring GHG Emissions (2014), Official Gazette, 29003, May 17, 2014.

D) Country-Level/National GHG Inventories

The concept of GHG accounting at the country-level emerged with the establishment of the UNFCCC in 1994. With the ultimate goal of the UNFCCC to stabilize atmospheric GHG concentrations at a level that would avoid dangerous anthropogenic interference with the climate system, estimation of national GHG emissions has become a crucial part of the efforts to achieve this objective. Accordingly, parties to the Convention are committed to submit national reports to the Conference of Parties (COP), required contents of which differ for Annex-I and non-Annex I parties, due to the "common but differentiated responsibilities" principle of the Convention. In line with Articles 4 and 12 of the Convention, industrialized/developed countries (Annex I) must submit their national GHG inventory annually, starting from their base year, 1990, and all the years since (UNFCCC, 2016).

Furthermore, a long-term climate change adaptation goal has been agreed upon by 196 Parties that came together under the Paris Agreement in 2015, which requires each party to plan and communicate their post-2020 climate actions every five years. Reducing national GHG emissions forms the basis of these planned actions that are called "Nationally Determined Contributions (NDCs)" (UNFCCC, 2017).

Today, the major guideline for country-level GHG accounting, which is also taken as reference by several other standards and frameworks for CF accounting at different levels, is the *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* The IPCC Guidelines were established essentially for the use of UNFCCC Parties to estimate and report their GHG inventories to the Convention. In addition, the "*2016 EMEP/EEA*[18] *Air Pollutant Emission Inventory Guidebook"* was established within the scope of the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP), which has been signed by Turkey in November 13, 1979; and has been

[18] EMEP/EEA stands for "European Monitoring and Evaluation Programme/European Environment Agency"; which is a cooperative programme for monitoring and assessing the long-range transmission of air pollutants in Europe. EMEP is a scientific body established under the CLRTAP (EEA, 2016).

ratified in April 18, 1983 (The United Nations Economic Commission for Europe , 2012). The 2006 EMEP/EEA Guidebook is the latest version of the original Guidebook published in 1992; and is compatible with the 2006 IPCC Guidelines. It is also recommended by IPCC Guidelines as a source of air pollution emission factors for the indirect GHGs (i.e. ozone precursors and sulphur dioxide) to the Parties that report under UNFCCC (TFEIP Secreteriat, n.d.). Although the Guidebook is a general reference source; it is essentially designed to facilitate reporting of emission inventories by countries to the CLRTAP; and is also used by the EU Member States for reporting under the EU National Emission Ceilings Directive (EEA, 2016). Since country-level CF accounting is not directly related with the objective of this thesis, details of the methodologies will not be further discussed.

APPENDIX C

CALCULATION OF UNIT AREA-BASED CONSUMPTIONS

INDIVIDUAL HEATING (IH) ELECTRICITY CONSUMPTION 2014-2017 (kWh)

Sayaç Seri No	Abone No	2014/01	2014/02	2014/03	2014/04	2014/05	2014/06	2014/07	2014/08	2014/09	2014/10	2014/11	2014/12	2014 Toplam
		246.867	209.899	200.545	200.749	192.025	177.776	2.123	202.232	104.957	152.032	165.624	101.428	1956.257
		262.605	209.127	180.623	153.595	215.914	163.31	173.147	141.484	154.991	151.585	141.393	123.166	2070.94
		314.492	292.766	254.878	240.281	229.394	213.633	247.821	108.806	128.365	208.347	205.345	160.467	2604.595
		185.821	146.828	159.887	149.522	153.324	136.119	117.751	120.076	164.777	123.708	155.071	124.861	1737.745
		556.237	408.69	449.911	405.254	380.359	366.441	400.039	395.202	416.022	435.123	359.228	290.358	4862.864
		298.147	293.043	256.538	269.807	286.511	357.193	380.734	378.543	396.027	305.841	245.186	230.702	3698.272
		266.725	234.016	227.134	219.948	212.374	198.779	254.647	439.265	361.928	194.374	185.218	157.638	2952.046
		302.332	253.862	210.195	209.02	183.325	148.155	78.345	83.299	83.166	192.318	166.033	145.964	2056.014
		241.748	186.177	211.864	207.048	194.109	173.986	195.731	186.236	204.121	172.94	147.921	134.012	2255.893
		223.183	193.455	181.785	169.458	162.258	154.451	157.961	193.551	192.823	181.897	160.025	182.038	2152.885
		241.279	192.026	250.391	242.742	199.737	174.164	145.035	111.093	153.196	180.961	182.063	154.136	2226.823
		257.232	216.79	131.982	169.662	139.439	163.645	147.14	164.124	119.126	158.644	131.701	138.137	1937.622
		313.033	293.932	293.969	283.32	266.656	222.906	237.814	330.993	303.795	305.805	243.298	231.912	3327.433
		341.294	329.603	325.233	361.162	343.5	320.167	270.316	368.334	332.974	314.827	250.865	205.893	3764.168
		128.032	69.93	82.3	119.808	107.092	92.24	113.538	143.158	106.736	100.258	96.274	77.662	1237.028
		213.721	181.342	209.148	199.796	179.054	179.384	152.098	57.443	106.221	178.519	193.838	164.999	2015.563
		238.248	167.588	190.161	191.987	196.924	164.945	191.602	155.194	169.957	177.887	185.089	160.601	2190.183
		183.267	150.305	129.82	143.954	119.278	117.148	129.04	237.744	211.003	133.712	115.861	92.552	1763.684
		184.585	156.648	140.324	143.719	159.252	41.484	93.687	61.709	122.487	44.88	55.839	100.675	1305.289
		214.494	187.966	161.19	141.559	151.57	134.537	155.183	122.896	124.495	153.037	119.602	122.023	1788.552
		251.307	206.895	209.678	214.462	197.798	224.657	192.341	239.881	237.025	253.718	198.003	172.479	2598.244
		266.876	193.892	187.279	192.688	166.242	161.45	171.212	400.689	177.046	183.03	156.259	128.211	2384.874
		313.977	287.747	245.386	216.103	206.993	203.429	183.74	274.546	232.745	243.381	235.301	227.623	2870.971
		196.494	133.279	149.693	144.111	133.899	126.465	147.847	132.733	144.904	132.409	110.47	108.834	1661.138
		324.649	314.327	282.76	287.566	282.628	259.093	234.961	249.606	260.236	258.24	223.01	212.028	3189.104
		161.26	146.035	140.853	146.658	121.332	135.277	131.455	152.166	145.391	120.946	112.175	93.907	1607.455
TOPLAM		**6727.905**	**5656.168**	**5463.527**	**5423.979**	**5180.987**	**4810.834**	**4705.308**	**5451.003**	**5154.514**	**5058.419**	**4540.692**	**4042.306**	**62215.642**

TOTAL AREA	
Floor area*total #	3174

CONSUMPTION CALCULATIONS
COMMON SPACES INCLUDED

Parameter	Year	Result	Year	Result	Year	Result	Year	Result	Year	Result
Consumption per unit area (kWh/m2)	2017	20.60	2016	19.88	2015	20.15	2014	19.60	2014-2017 avg	20.06

INDIVIDUAL HEATING (IH) NG CONSUMPTION 2014-2017 (Sm3)

Dış Kapı No.	Daire No	2014/01	2014/02	2014/03	2014/04	2014/05	2014/06	2014/07	2014/08	2014/09	2014/10	2014/11	2014/12	2014 Toplam
		229.94	181.71	152.48	110.25	45.66	18.98			58.42	19.65	32.95	105.59	955.63
		211.38	156.79	144.18	121.59	51.75	27.98			29.21	0	45.5	96.45	884.83
		156.73	27	45.64	90.68	39.57	21.98			47.71	18.66	19.97	52.8	520.74
		336.15	175.48	147.29	92.74	46.67	18.98			27.26	0	42.53	116.76	1003.86
		225.82	113.18	97.5	70.07	28.41	17.99			37	0	40.55	91.38	721.9
		133.02	92.41	79.87	62.86	29.42	0				0	22.61	84.27	504.46
		248.5	143.3	163.89	125.71	49.72	23.98			38.95	21.61	49.93	126.91	992.5
		217.57	155.76	169.08	145.29	97.4	43.96			23.37	20.63	59.92	142.14	1075.12
		145.39	92.41	71.57	47.4	0	24.18			36.03	0	29.67	47.72	494.37
		170.14	138.1	106.84	66.98	26.38	18.98			24.34	0	31.65	66	649.41
		215.51	112.14	124.47	131.89	89.29	20.98			40.89	0	25.72	55.84	816.73
		199.01	93.45	113.06	108.19	22.32	18.98			35.05	20.63	28.96	82.24	721.89
		255.72	194.18	187.75	180.32	104.5	39.97			63.29	19.65	51.93	155.34	1252.65
		223.76	161.99	148.33	91.71	29.42	26.98			53.55	19.65	48.93	147.22	951.54
		191.79	118.37	107.88	74.19	32.47	18.98			51.6	22.59	37.95	93.41	749.23
		181.48	109.03	80.91	48.43	24.35	15.99			30.18	0	29.67	47.72	567.76
		44.34	25.96	25.93	24.73	23.34	15.99			41.87	17.68	0	59.45	279.29
		195.92	116.3	93.35	84.49	32.47	0				27.45	18.97	74.12	643.07
		214.004	136.372	121.707	102.355	49.187	24.037			40.506	17.58	15.98	22.34	744.068
		140.24	118.37	114.1	97.89	52.76	23.98			33.1	0	28.68	68.03	677.15
		218.6	179.64	142.11	130.86	42.61	24.98			49.66	20.63	36.95	115.75	961.79
		238.19	164.06	149.37	120.56	67.98	23.98			26.29	0	43.52	125.9	959.85
		388.74	250.25	244.8	239.06	135.96	32.97			33.1	30.45	94.87	205.09	1655.29
		409.36	209.75	108.91	123.65	27.39	0			39.19	0	49.46	130.97	1098.68
		158.8	143.3	101.65	66.98	31.45	23.98			71.08	24.56	23.97	28.43	674.2
TOPLAM		**5350.104**	**3409.302**	**3042.667**	**2558.875**	**1180.477**	**528.807**	**0**	**0**	**931.646**	**301.42**	**910.84**	**2341.87**	**20556.008**

TOTAL AREA	
Floor area*total # of storeys	3174

CONSUMPTION CALCULATIONS

Parameter	Year	Result	Year	Result	Year	Result	Year	Result	Year	Result
Consumption per unit area (kWh/m2)	2017	7.96	2016	6.99	2015	7.00	2014	6.48	2014-2017 avg	7.10

APPENDIX D

CARBON FOOTPRINT CALCULATIONS

FID	BINA_ISINMA	TOPLAM_DAIRE	Population_DU	KAT_SAYISI	Elec_Cons	NG_Cons	Elec_EF	NG_EF	CF_Elec	CF_NG	Total_CF	Percap_CF	Area
3806	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.55	21.03	37.58	0.95	295
3805	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.55	21.03	37.58	0.95	295
3804	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.50	20.96	37.46	0.95	294
3803	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.55	21.03	37.58	0.95	295
3802	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.55	21.03	37.58	0.95	295
3801	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.55	21.03	37.58	0.95	295
3800	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.50	20.96	37.46	0.95	294
3799	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.55	21.03	37.58	0.95	295
3798	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.55	21.03	37.58	0.95	295
3797	D	12	39.6	6	17.13	5.53	0.5459	2.1488	16.55	21.03	37.58	0.95	295
3796	M	16	52.8	7	16.55	6.05	0.5459	2.1488	26.94	38.77	65.71	1.24	426
3795	M	16	52.8	7	16.55	6.05	0.5459	2.1488	26.18	37.67	63.86	1.21	414
3794	D	72	237.6	18	17.13	5.53	0.5459	2.1488	207.21	263.30	470.51	1.98	1231
3793	D	72	237.6	18	17.13	5.53	0.5459	2.1488	207.37	263.51	470.89	1.98	1232
3792	D	72	237.6	18	17.13	5.53	0.5459	2.1488	206.20	262.02	468.21	1.97	1225
3791	D	72	237.6	18	17.13	5.53	0.5459	2.1488	206.36	262.23	468.59	1.97	1226
3790	D	72	237.6	18	17.13	5.53	0.5459	2.1488	206.87	262.87	469.74	1.98	1229
3789	D	72	237.6	18	17.13	5.53	0.5459	2.1488	206.36	262.23	468.59	1.97	1226
3788	D	72	237.6	18	17.13	5.53	0.5459	2.1488	205.69	261.38	467.07	1.97	1222
3787	B	4	13.2	2	19.88	6.99	0.5459	2.1488	2.32	3.21	5.54	0.42	107
3786	B	4	13.2	2	19.88	6.99	0.5459	2.1488	2.54	3.51	6.05	0.46	117
3785	B	4	13.2	2	19.88	6.99	0.5459	2.1488	2.34	3.24	5.59	0.42	108
3784	B	4	13.2	2	19.88	6.99	0.5459	2.1488	2.41	3.33	5.74	0.44	111
3783	B	4	13.2	2	19.88	6.99	0.5459	2.1488	1.98	2.73	4.71	0.36	91
3782	M	28	92.4	7	16.55	6.05	0.5459	2.1488	38.83	55.88	94.71	1.02	614
3781	M	20	66	10	16.55	6.05	0.5459	2.1488	40.20	57.85	98.06	1.49	445
3780	M	20	66	11	16.55	6.05	0.5459	2.1488	44.22	63.64	107.86	1.63	445
3779	M	28	92.4	7	16.55	6.05	0.5459	2.1488	54.77	78.81	133.58	1.45	866
3778	M	15	49.5	5	16.55	6.05	0.5459	2.1488	24.57	35.36	59.93	1.21	544
3777	B	18	59.4	9	19.88	6.99	0.5459	2.1488	28.91	40.01	68.92	1.16	296
3776	B	18	59.4	9	19.88	6.99	0.5459	2.1488	28.91	40.01	68.92	1.16	296