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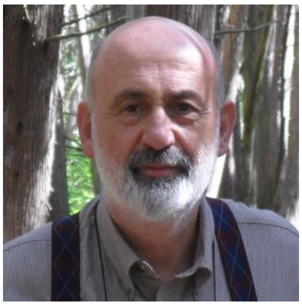

Tanay Sıdkı Uyar

Conference Chair,
IRENEC 2023

Dear Participants,

In our journey of promoting 100% Renewable Energy, we have arrived the 13th stop where we shall again share our research results and other achievements.

Every day we are discovering and practicing the good quality of renewable energies. The genie is out of the bottle. It is time to use the good quality of human beings to guide this opportunity effectively to the destination. The qualities of human beings can play its role if the individuals and countries talk together and define problems correctly and find solutions that can be implemented.

Renewable energy resources at each corner of the atmosphere are ready to be converted to electricity and process heat locally when needed. Kinetic energy of the moving air, chemical energy stored in biomass, heat and light of the sun and geothermal resources are available all over our planet earth free of charge. As the main energy source of living space on earth, sun and its derivatives were available before, are available today and will be available in the future.

Global support provided for the renewable energy made the market penetration of renewables possible. Today wind and solar energy became the cheapest way of producing electricity in many parts of the World.
Cities and countries who are trying to reach 100% renewable energy mix are working on preparing the infrastructure necessary to be able to supply more renewable energy for industry, transportation and buildings by smart grids and renewable energy storage systems.

Since renewable energy is available at every corner of our atmosphere, Community Power (the involvement of the local people individually or through their cooperatives and municipalities in the decision-making process and ownership of their energy production facilities) is becoming the most effective approach for transition to 100% renewable energy future.

During IRENEC 2023 we shall share and learn from the global experiences on difficulties, barriers, opportunities and solutions for transition to 100 % renewable energy societies and make our contribution to Global Transition to 100% Renewable Energy.

Best Regards,

Tanay Sıdkı Uyar

Conference Chair, IRENEC 2023

President, Renewable Energy Association of Turkey

(EUROSOLAR Turkey)

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EU4 Energy Transition and Multistakeholder Partnership for Climate Resilient Cities in Türkiye

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For many Turkish cities, climate change is becoming important issue and local level can significantly contribute by preparing and implementing Sustainable Energy and Climate Action Plans (SECAPs) by the Covenant of Mayors initiative.

The Global Covenant of Mayors (GCoM) in cooperation with the EU Covenant of Mayors for Climate & Energy (CoM EU) are the largest global alliance for city climate leadership, built upon the commitment of over 10,000 cities and local governments. With nations working towards the goals of the Paris Climate Agreement, cities' involvement could not be more urgent. In order to transform their political commitment into practical way, covenant signatories- municipalities preparing roadmap-strategic document SECAP in which is identified mitigation, adaptation actions and important third pillar how to reduce energy poverty. So, cooperation and Multistakeholder Partnership for Climate Resilient Cities are crucial. "EU4 Energy Transition: Covenant of Mayors in the Western Balkans and Türkiye"(EU4ETTR) project supported by European Union (EU) and the German Federal Ministry for Economic Cooperation and Development (GIZ) and implemented by the Central Project Management Agency of Lithuania in Türkiye. EU4ETTR project will tackle climate change and support the energy transition in the Western Balkans and Türkiye through an increased uptake of the Covenant of Mayors for Climate and Energy Initiative (CoM) in the region and support municipal authorities to translate their ambitions to reduce greenhouse gas (GHG) emissions into SECAPs and enhance resilience to climate change impacts, while taking into account diversity on the ground. Within the project, a comprehensive cooperation model for Turkish municipalities and other process participants to implement SECAPs in Türkiye and overcome the technical and organizational good background. A "Multi-Level Governance Platform" (MLGP) is structure in the country could convey guidelines for the municipalities to achieve their targets. MLGP is a mechanism that facilitates the ability for national, regional, and local governments to work effectively with other key stakeholders. In order to effectively design and implement climate policies, it is important to ensure both vertical and horizontal collaboration. The goal of the MLGP is also to foster knowledge of the demands of the various levels and groups of stakeholders such as non-governmental organizations and private sector.

Keywords: Covenant of Mayors, Sustainable Energy and Climate Action Plan (SECAP), Multi-Level Governance Platform (MLGP), Energy Transition, Sustainable Energy, Climate Change

1 The Impact of Cities on Climate Change

Cities contain more than half of the world's population and they consume more than two thirds of the world's energy. Local leaders around the world are pursuing ambitious climate initiatives in their communities. Cities are key to deliver on the Paris Agreement and the Sustainable Development Goals (SDGs) of the United Nations (UN) 2030 Agenda. All levels of government – cities, regions, and central level – have a role to play when it comes to raising the bar and working hand-in-hand with the scientific community, financial institutions, and the private sector.

The energy transition is changing the everyday life of politics and society. Policy must balance competing goals and values. Only if approaches are objective, comprehensible and sustainable, both environmentally, fiscally, and socially, will the population support the energy transition. In addition, cities are extremely vulnerable to the impacts of climate change, as they concentrate people and assets. Strengthening cities' resilience, enhancing their adaptive capacity, and improving preparedness against climate change impacts is urgent. This change in paradigm requires an early, transparent dialogue with all stakeholders.[1]

Cities and municipalities in Türkiye are in the position to play an essential role in establishing this dialogue. Moreover, given the major challenge of urban growth in the coming decades, local governments' planning capacities on urban design, climate resilience and disaster preparedness, mobility and energy (power and heating/cooling systems) have to increase. These are key drivers for a successful climate action, both in mitigation and in adaptation, and lay at the core of the Covenant of Mayors (CoM) initiative.

There is enormous potential for expanding renewable energies and improving energy efficiency. Resources such as water, energy, land, and forests constitute the foundations of world economies and the livelihood of many people in Türkiye and across the world depend on them. Although Türkiye has some level of preparation in environment and climate change area and there has been some progress, mainly in increasing capacity in waste management and wastewater treatment as well as legislative alignment, enforcement and implementation still remain weak. Furthermore, Türkiye's greenhouse gas emissions doubled over the last decade. More ambitious and better coordinated environment and climate policies need to be established and implemented. At the same time, the country is located in one of the most vulnerable regions as for the impact of climate change. Therefore, in Türkiye even more than in other plac-

[1] *Revised Indicative Strategy Paper for Turkey (2014-2020) adopted on 10/08/2018; Turkey 2019 Report, Brussels, 29.5.2019 (COM (2019) 260 final); Climate Change Strategy (2010-2023), Republic of Turkey.*

es, timely and ambitious climate action is necessary to achieve a competitive, resource-efficient, and low-carbon economy, and a resilient society.

2 EU4Energy Project: Activities and Multistakeholder Partnership for Climate Resilient Cities in Türkiye

2.1 The Role of Local Authorities for Climate Resilient Cities

Local leaders in Türkiye have a common vision for creating resilient, low-carbon cities where people have access to safe, cheap energy and are ready for the effects of climate change. They promised to lower CO2 emissions by a percentage that will be decided upon, according to the degree of ambition agreed upon at the EU level (40% by 2030 and beyond, in accordance with the EU's ambitious aims), and to strengthen their resilience to the effects of climate change. The synergies between renewable energy transition, GHG emission reductions, and better air in urban settings are the foundation of this concept.

Cities are particularly sensitive to the effects of climate change because they prioritize protecting people and assets. It is critical to increasing urban resilience, the ability for adaptation, and climate protection. All parties must engage in an early, open discourse regarding this paradigm shift. While considering local diversity, "EU4 Energy combats climate change, supports the energy transition in the Western Balkans and Türkiye through increased adoption of the Covenant of Mayors for Climate and Energy Initiative (CoM) in the region, aids municipal authorities in bringing their goals to reduce greenhouse gas (GHG) emissions to life, and strengthens resilience to the effects of climate change.

Türkiye's cities and municipalities are able to play a crucial part in developing this discourse. Although Türkiye has made some planning for the environment and climate change and has made some headway, particularly in expanding waste management and wastewater treatment capacity and aligning regulatory frameworks, enforcement and implementation continue to lag behind.

Additionally, local governments' planning capabilities in the areas of urban design, climate resilience and disaster preparedness, transportation, and energy (electricity and heating/cooling systems) must be improved given the significant challenge of urban expansion in the ensuing decades. These are essential ingredients for effective climate action, both in terms of adaptation and mitigation, and they form the basis of the CoM effort.

In Türkiye, policies for sustainable development are included in many laws, legislations, regulations, policy papers, and action plans across many different policy disciplines and sectors.

Additionally, during the past ten years, Türkiye's greenhouse gas emissions have doubled. Environment and climate policies need to be developed and put into action in a more ambitious and well-coordinated manner. In line with EU Member States, municipalities from Türkiye have been joining CoM, developing Sustainable Energy and

Climate Action Plans (SECAPs) and relying on the MyCovenant platform for progress reporting.
However the process of SECAP development and implementation has been slow, facing many challenges, thus resulting in unachieved CO2 emission reduction targets and limited adaptation action.
The lack of capacity and expertise, and lack of mutual cooperation among all players, both technical and operational, has been confirmed during round table discussion wich was conducted with partners from municipalities, associations of municipalities, national level experts, representatives from academia. The development of a SECAP, and later its financing and implementation is a big challenge to reach the Covenant of Mayors targets for cities anywhere in the world. Based on the experiences from CoM Europe and CoM East initiatives, the following are some of the main reasons:

1. Municipalities lack capacities to develop, implement and monitor SECAP.
2. There is a lack of monitoring actions at all levels of implementing climate change action plans.
3. There is essential to establish a vertical governance system from bottom up to top where national authorities get data from municipalities and municipalities provide proper data to them. However even if this system is established, it is crucial for national authorities to give legal authorization to municipal authorities for construction and protection actions.
4. There is lack of empowering municipalities to develop their independent financial and technical instruments in buildings renovations, renewable energy technologies such as storing rainwater, solar panel construction in residential buildings by receiving funds from municipalities.
5. Municipalities are lacking support from national level institutions by solving citizens' problems or trying to implement various instruments related to climate change agenda.
6. Municipalities lack capacities and support from the governments and donors to develop innovative financing schemes, to involve private investors and catalyse private investments by stakeholders on their territories.
7. There is a lack of funding for small-scale projects at central or municipal level.
8. There is the lack of an enabling regulatory framework and enabling administrative processes, clear mandates, and responsibilities.
9. There is lack of cooperation actions between national and municipal level in planning climate change actions. There is a crucial need for an exchange of information about planned measures, about provided data relevant and interpretation, about integration of actions etc.
10. There is crucial need for systematic approach and storage in one place of all information, methodologies, tools, data, working meetings minutes during planning of climate change agendas, as well implementations and monitoring stages.

A core methodological principle of the project is to strengthen the learning process and increase the capacity of local authorities in Türkiye to meet their commitments under the energy and climate targets as well as to increase resilience by adapting to the impacts of climate change.

By joining the initiative, cities commit themselves to contribute to the EU's climate protection goals and to develop and implement a SECAP. In this context, one of the key activities of the project is the provision of advisory services and technical and capacity support to selected municipalities in Türkiye in the development of their first SECAPs (see Fig. 1).

Fig. 1. Steps of development of SECAP

EU4Energy Transition project was launched in 2021. Since the beginning of the project, the number of signatories to the Covenant of Mayors in Türkiye has doubled. The rapid increase in the interest of Turkish municipalities in the Covenant of Mayors plays a key role in the success of the steps to be taken for 40% CO2 reduction by 2030.

When it comes to climate change, it is very important to act together to achieve the goals. While the project provides capacity building in the SECAP of local authorities, it also brings together the relevant parties. With the multi-governance platform created within the scope of the project, some selected municipalities from across Türkiye and parties such as ministries, municipal unions, and academy representatives will be brought together and an exchange of ideas will be provided.

To establish a functioning regional cooperation between CoM initiatives and municipalities in Türkiye, EU4ETTR project started to prepare strategy to a wider engagement of stakeholders. The project supports the creation of the Multi-Level Governance Exchange Platform, which enables municipalities to strengthen their presence in national planning. The available instruments are used to establish a link between the national and local levels, and some of them are: participation of local government representatives in meetings of working groups preparing the NECP; participation in presentations and public discussions; organization of a meeting to coordinate the collection of data relevant to both NECP and SECAP documents; establishment of a regular exchange of information through the appointment of focal points in participating municipalities. In addition to the role of the municipal associations as intermediaries for their members, the action strengthens their role as advocacy for the needs of local authorities at national level.

2.2 Stakeholder Engagement Strategy

Within the scope of stakeholder engagement strategy, the Multi-Level Governance Platform (MLGP) has been established and initially facilitated by the project team. Initially, a pilot at a relatively small scale (<20 municipalities) will be developed as a test phase to identify and eliminate challenges. After a year, this phase will be finalised, and upscaling will take place nationally.
Since the project is established and aiming initially at Istanbul Metropolitan Municipality and Bağcılar Municipality and nearby municipalities, it is logical to aim at the Marmara Region first. Therefore, the MLGP governed by the nearest regional union of municipalities of which a considerable number of member municipalities are already active in the project. This is the Marmara Union of Municipalities (MMU). This must be done together and supported by the project management organization. When the MLGP is fully fledged, and its outcomes are monitored and analyzed, and it can be expanded to the national level. At that moment the project could be governed by the Turkish Union of Municipalities (UTM), which advised it to be included in the Advisory Committee during the pilot phase. The MLGP of the Marmara Region could remain intact for the municipalities of that region and could provide support to the national MLGP when desired.
As summarized above, Multi-Level Governance Platform establishment starts with the implementation of a pilot testing platform and then it will be distributed all cities in Türkiye.
Multi-Level Governance Platform establishment started with a physical survey conducted which was jointly organized with MMU and there were 69 participants from 33 municipalities from the Marmara region of Türkiye. Participants were asked survey questions about MLGP. As a result of 2 round of online surveys and 1 physical survey, international and local experts analyzed all results and prepared a Multi-Level Governance Platform Report.
The report includes;

1. Multi-Level Governance Platform definition,
2. Organizational structure,
3. Requirements of a MLPG in Türkiye from a stakeholders' perspective
4. 2023 Gantt scheme with concrete actions with expected results and indicators.

The EU4ETTR-partners that are needed to join the Multi-level Governance Platform and what expectations and needs they have, the activities that need to be organized and the ways for communication that are preferred have been defined.

The results of the survey analysis revealed that in order to describe processes and structures that apply to Türkiye's government, it is important to know what the structure is. In Türkiye, 8 levels of administration are present, regarding national, provincial, municipal and village level. These include:

1. The national government with ministries
2. Provincial Administration
3. Municipal and village governments, comprising of:

a. Metropolitan Municipalities
b. Metropolitan-District Municipalities
c. Provincial Municipalities
d. District Municipalities
e. Town Municipalities
f. Village Administrations (not municipalities, but with a Council of Alderman and Village Mukhtar)

Furthermore, it is of importance to know that:

- There is one national Union of Municipalities of Türkiye (UTM) of which each municipality is obliged to be member of;
- Municipalities can form associations among themselves for environmental protection, waste disposal services and other infrastructure services. Those associations are granted legal personality.

After above analysis, stakeholder analysis was conducted. The stakeholder analysis showed that the stakeholders of importance for a structure to support the Climate Action Plan process mentioned by the consulted stakeholders themselves, can be divided over 8 main groups:

1. National Governmental bodies
2. Provinces
3. Municipalities
4. Governmental platforms and unions (nationally and internationally)
5. Academia
6. Companies
7. NGOs
8. Others.

The latter group ("others") is broad and includes: citizen participation, international organisations, international development agencies, OIZ administrations and associations), cooperative representatives and organizations for the rural areas. Also, as a result of two-round surveys, the general needs and concerns that were shared by the stakeholders include;

1. Enhanced cooperation and coordination between the stakeholders and monitoring of SECAP implementation,
2. Establishment of joint working groups,
3. Providing the necessary information training to the SECAP team, (including: providing support in the establishment of the data collection and monitoring system, sharing the training presentations),
4. Continuity of the platform

3 For Stronger Multistakeholder Partnership: Peer to peer model with Turkish CoM municipalities

3.1 Analysis of CoM Municipalities in Türkiye

EU4 Energy Transition project in close cooperation with Marmara Municipalities Union and Union of Municipalities of Türkiye started implementation in Türkiye.
Two main beneficiary municipalities İstanbul Metropolitan Municipality and Bağcılar Municipality are receiving technical assistance to combat climate change and implement climate actions.
The rest of the applicant municipalities become "observer municipalities" to receive knowledge and capacity building.

Online surveys are nowadays being used to make an assessment for larger audiences. Thus, EU4ETTR project uses online tool to learn from observers about their approach to SECAP.

According to the survey conducted within observer municipalities, observers think below are the challenges of the process:

- Setting up a team
- Preparatory activities for the initiation of the procedure (political will, coordination, professional resources, participants, etc.)
- Monitoring and control of the identified measures

Fig. 2. Main challenge of achieving a successful internal organization

As it can be seen from Fig. 2, the most challenging issue for municipalities to reach a successful internal organization for SECAP preparation is to building a team. Most municipalities, especially district municipalities in rural regions of Türkiye has lack of capacity in terms of technical staff which doesn't allow them to prepare SECAPs on their own. In order to solve this problem, municipalities have to hire technical staff with specific knowledge on SECAP preparation. However, as Türkiye is recently getting more involved in CoM initiative only in the last 2 years, it is challenging to find staff who have enough knowledge to prepare technical parts of a SECAP. As a solution, municipalities could lead their technical staff to online trainings about SECAP preparation which are organized by international organizations such as Joint Research Center, CoM, EU Commission etc. It would be also beneficiary to build relations with Turkish municipalities who completed their SECAPs to collect information from them.

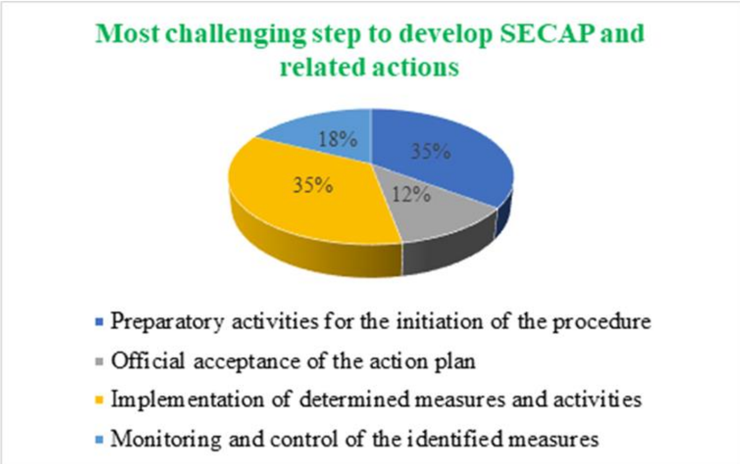

Fig. 3. Most challenging step to develop SECAP and related actions

According to the results, Fig. 3 display the most challenging steps to develop SECAP and related actions are the preparatory activities for the initiation of the procedure, and also same ratio for the implementation of determined measures and activities. This shows that municipalities need technical expertise in SECAP preparation activities as data collection procedures are very time-consuming and not efficient due to the lack of data sharing between institutions. To solve this problem, regular data collection in every 6 months could be good to keep up-to-date data within the municipality records to use every year for inventory calculations.

Observers believe the following sections of SECAP are most time-consuming to write:

- Baseline Emission Inventory (BEI)
- Adaptation Actions

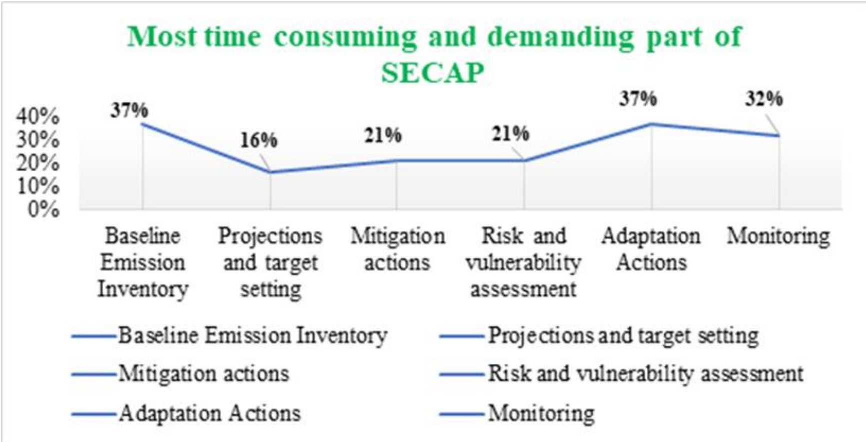

Fig. 4. Most time consuming and demanding part of SECAP

Fig. 4 shows that municipalities' related departments spend most of their time during SECAP preparations for baseline emission inventory and adaptation actions parts. This is common ground for most CoM signatory municipalities as data collection procedures are very time-consuming especially from external institutions or municipal stakeholders. As it is mentioned for the previous figure, data collection procedures could be fastened by increasing strong communication with stakeholders and to assign 1-2 persons for data collection and providing from each institution. Also, an online data monitoring tool could be used among all municipality and municipal stakeholder institutions where data could be monitored remotely.

For a SECAP to be successful, observers think the following needs to be achieved:

- Financing of actions
- Implementation of actions
- Monitoring of actions

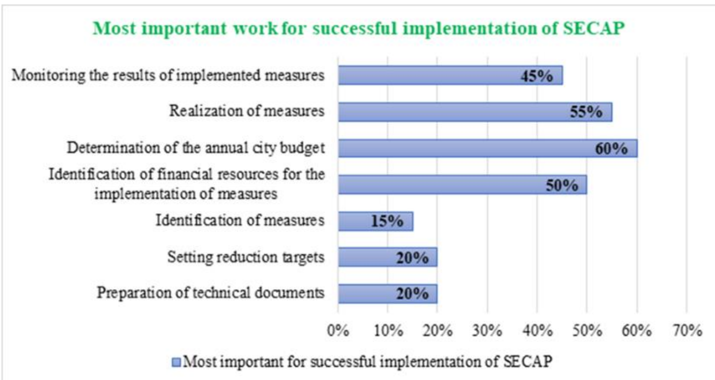

Fig. 5. Most important work for successful SECAP implementation

Fig. 5 presents the most important activities for successful SECAP implementation. The most crucial action is the determination of the annual city budget which is related with the financing of the implementation measures. The challenge here is related with the interest of municipality management board to environment-related topics and their willingness to share a budget for the specific activities for climate actions. To overcome this problem, municipality SECAP teams could regularly inform higher management about recent developments about climate actions among Türkiye and in their regions and also inform them about possible external funding options. If they recognize the problem, they have the authority to dedicate the required budget.

Observers want to have external support in the following topics:

- Financing of actions
- Implementation of measures
- SECAP monitoring
- Arrangement of internal organization

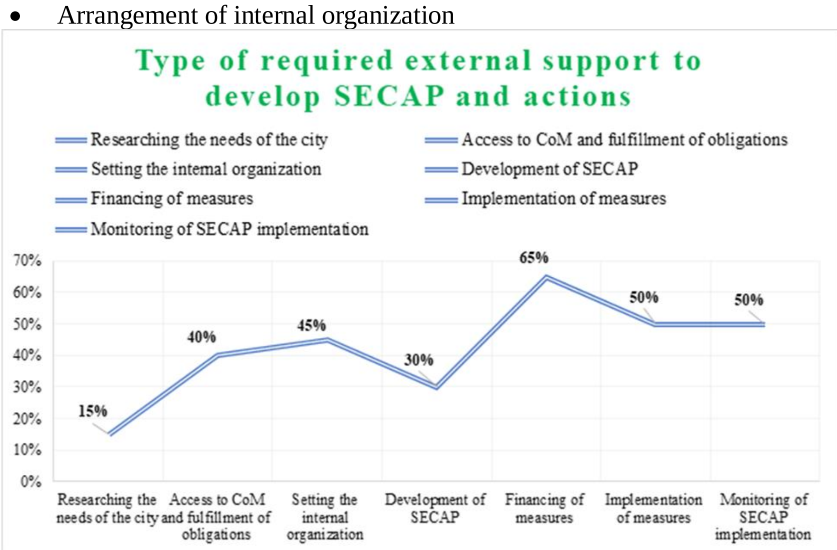

Fig. 6. Required external support type to develop SECAP and actions

Fig. 6 shows that municipalities have not sufficient budget for implementing the measures of SECAP. This is the common case for most of the rural area municipalities in Türkiye where the municipality budget is divided for other priority activities such as infrastructure, transportation, social works and not enough budget for environment-related actions. In order to overcome this problem, these municipalities should follow international funds from World Bank, EBRD, EU grant projects etc. and follow these institutions' websites regularly to apply many of them.

Municipalities want the external support to be provided by the following means:

- Best practice examples
- Tutoring and peer support activities
- Conferences, seminars, workshops, training sessions

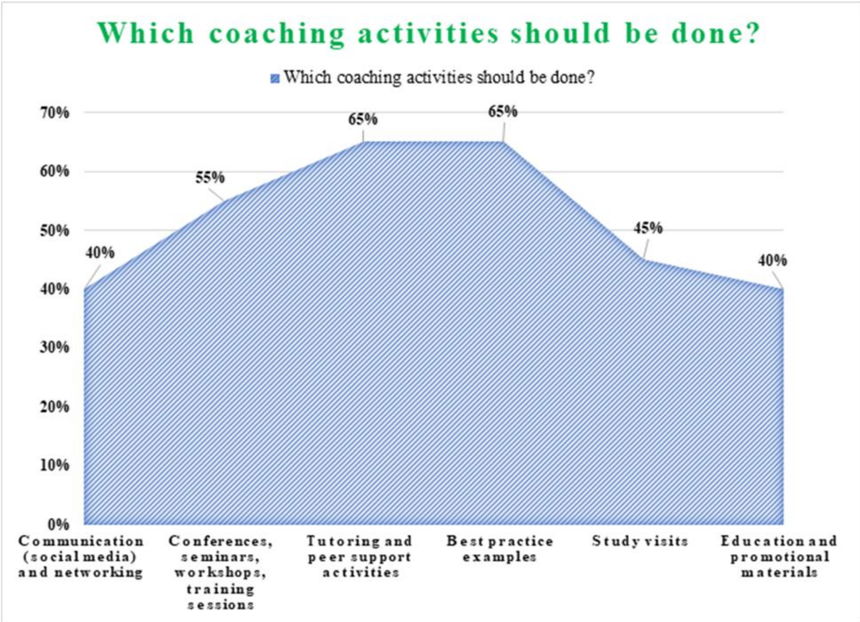

Fig. 7. Necessary coaching activities

Fig. 7 presents the type of coaching activities that municipalities need to receive from external projects. The results show that they would like to receive support by seeing best practice examples and also by tutoring and peer-to-peer activities. In order to get such coaching activities, they should follow externally funded projects to be included in these projects and visit other countries' facilities.

3.2 Capacity Increase Activities of Turkish Municipalities

According to the interviews conducted with Turkish Municipalities, they have challenges and obstacles in all steps of SECAP. In order to overcome this problem, wider engagement of observers into the project seems necessary. In line with the strategy, the Project will be working more closely and in strong cooperation with 20 observer municipalities in 2023 to provide them support for SECAP preparation, implementation of actions, deliver information about possible financial resources. In return, the Project expects to have a SECAP at the end of the year from the municipalities who haven't completed or even started preparing their SECAPs.

The capacity building activities for the observer municipalities will be interlocked with the SECAP training activities to be realized for the test municipalities. Within the scope of capacity building activities, a SECAP-related subject will be focused on each month throughout 2023. Trainings will be organized in accordance with the subject of the relevant month, and technical consultancy will be provided to the observer municipalities throughout the month. The aim of these activities is to ensure that the SECAPs are completed by the end of 2023 and that the approaches related to implementation and monitoring, which are the processes after the plan preparation, are also included in the plans.

4 Key Findings

- Cities are particularly sensitive to the effects of climate change because they prioritize protecting people and assets. It is critical to increasing urban resilience, the ability for adaptation, and climate protection. All parties must engage in an early, open discourse regarding this paradigm shift. While considering local diversity, EU4 Energy combats climate change, supports the energy transition in the Western Balkans and Türkiye through increased adoption of the Covenant of Mayors for Climate and Energy Initiative (CoM) in the region, aids municipal authorities in bringing their goals to reduce greenhouse gas (GHG) emissions to life, and strengthens resilience to the effects of climate change.
- A core methodological principle of the project is to strengthen the learning process and increase the capacity of local authorities to meet their commitments under the energy and climate targets as well as to increase resilience by adapting to the impacts of climate change.
- The number of signatories to the Covenant of Mayors in Türkiye has doubled within 2 years. The rapid increase in the interest of Turkish municipalities in the Covenant of Mayors plays a key role in the success of the steps to be taken for 40% CO2 reduction by 2030.
- To ensure long-lasting results, Türkiye must not only have administrative and institutional capacity to draft the Sustainable Energy and Climate Action Plans (SECAPs) but should also ensure effective implementation of SECAPs. In addition, a climate and energy supporting structure will have to be able to provide coordination, and capacities to develop, implement and monitor SECAPs.
- The project supports the creation of the Multi-Level Governance Exchange Platform, which enables municipalities to strengthen their presence in national planning.
- MLGP at a relatively small scale (<20 municipalities) will be developed as a test phase to identify and eliminate challenges. After a year, this phase will be finalised, and upscaling will take place nationally.
- According to the interviews conducted with Turkish Municipalities, they have challenges and obstacles in all steps of SECAP. In order to overcome this problem, wider engagement of observers into the project seems necessary. In line with the strategy, the Project will be working more closely and in strong cooperation with 20 observer municipalities in 2023 to provide them support for capacity building in SECAP preparation, implementation of actions, deliver information about possible financial resources.

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Sustainable Energy and Climate Action Plan (SECAP) Perspective and Content for Turkish Municipalities

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Global Cities contain more than half of the world's population and they consume more than two thirds of the world's energy. Local leaders around the world are pursuing ambitious climate initiatives in their communities. Cities are key to deliver on the Paris Agreement, Green Deal Agenda and the Sustainable Development Goals (SDGs) of the United Nations (UN) 2030 Agenda. Municipalities in Türkiye are in the position to play an essential role in establishing climate actions.
Moreover, given the major challenge of urban growth in the coming decades, local governments planning capacities on urban design, climate resilience and disaster preparedness, mobility and energy (power and heating/cooling systems) have to increase. These are key drivers for a successful climate action, both in mitigation and in adaptation, and lay at the core of the EU Covenant of Mayors (CoM) and Global Covenant of Mayors (GCoM) initiative.

Local authorities joining the Covenant initiative commit to submit a Sustainable Energy and Climate Action Plan (SECAP) within two years following the formal signing, indicating a minimum 40% GHG emission reduction by 2030. The SECAP is based on a Baseline Emission Inventory (BEI) and a Climate Risk & Vulnerability Assessment(s) (RVAs) which provide an analysis of the current situation. These elements serve as a basis for defining a comprehensive set of actions that local authorities plan to undertake in order to reach their climate mitigation and adaptation goals. Signatories commit to report progress every two years. With respect to climate mitigation, local authorities are guided to address sectors such as the 'Residential', 'Tertiary', 'Municipal' and 'Transport', which are the key mitigation sectors.

The work presented in this paper is a product of EU4 Energy Transition: Covenant of Mayors in the Western Balkans and Türkiye Project. It is a multi-donor project that is jointly co-financed by the European Union and the German Federal Ministry for Economic Cooperation and Development and implemented by GIZ. This paper provides Covenant signatories with step-by-step guidelines throughout the SECAP preparation process in addition to some tips for Turkish municipalities.

Keywords: Covenant of Mayors, Sustainable Energy, Climate Change, SECAP, Green Deal, Energy Efficiency, Adaptation, Mitigation, GHG, Emissions

1 About Covenant of Mayors

Launched in 2008, the Covenant of Mayors is the world's largest movement for local climate and energy actions. As of today, more than 10,000 local and regional governments have joined the Covenant of Mayors. The Covenant of Mayors (CoM) was launched in 2008 to gather local governments voluntarily committed to achieve and exceed the EU 2020 climate and energy targets[2]. This meant mitigating CO_2 emissions through energy efficiency, renewable energies, and clean transport.

Under the initiative cities commit to meet and exceed the European objectives in terms of CO_2 emissions (at least 40% reduction by 2030), demonstrating a level of ambition often higher that on the national level in their respective countries. As signatories, they also sign up to a long-term 2050 vision of decarbonized and resilient cities with access to sustainable, secure and affordable energy. The Covenant of Mayors offers to cities a robust but at the same time flexible framework for planning and monitoring their actions in climate mitigation and adaptation areas. In their local Sustainable Energy and Climate Action Plans (SECAPs) cities design and take actions in the building sector, transport and local energy production, and implement adaptation measures. Unlike in many other initiatives, cities get scientific advice, and their actions are followed up and plans validated by the European Commission services. Addressing these key sectors and promoting an integrated approach, i.e. linking climate and energy action, the Covenant of Mayors aims also to increase sustainability in cities and communities.

The Global Covenant of Mayors for Climate & Energy (GCoM) is an international alliance of cities and local governments with a shared long-term vision of promoting and supporting voluntary action to combat climate change and move to a low emission, resilient society. The Global Covenant of Mayors for Climate & Energy formally brings together the European Union’s Covenant of Mayors and the Compact of Mayors – the world’s two primary initiatives of cities and local governments – to advance city-level transition to a low emission and climate-resilient economy, and to demonstrate the global impact of local action.

GCoM is the largest global alliance for city climate leadership, built upon the commitment of over 11,500 cities and local governments. These cities hail from 6 continents and 142 countries. GCoM envisions a world where committed mayors and local governments – in alliance with partners – accelerate ambitious, measurable climate

[2] https://eu-mayors.ec.europa.eu/en/about

and energy initiatives that lead to an inclusive, just, low-emission and climate-resilient future, helping to meet and exceed the Paris Agreement objectives[3].

Focusing on three pillars: mitigation, adaptation, and increased access to secure, affordable and sustainable energy, the GCoM supports implementation of ambitious, measurable and locally relevant solutions, captured through climate action plans developed, implemented and monitored by cities and local governments[4].

Turkish municipalities can choose to become a signatory of EU CoM or GCoM. Both initiatives are open to Turkish municipalities and provide capacity building activities. The work presented in this paper is a product of EU4 Energy Transition: Covenant of Mayors in the Western Balkans and Türkiye Project. It is a multi-donor project that is jointly co-financed by the European Union and the German Federal Ministry for Economic Cooperation and Development and implemented by GIZ. This project tackles climate change and support the energy transition in the Western Balkans and Türkiye through an increased uptake of the Covenant of Mayors for Climate and Energy Initiative (CoM) in the region and support municipal authorities to translate their ambitions to reduce greenhouse gas (GHG) emissions into reality and enhance resilience to climate change impacts, while taking into account diversity on the ground.

2 Reporting Frameworks

2.1 MyCovenant

Covenant of Mayors provides signatories with a data compilation and reporting framework which is unique in Europe. Covenant signatories are asked to use the Covenant of Mayors reporting platform – MyCovenant to report and monitor the data of their SECAP (further referred to as action plan), via the SECAP template. MyCovenant has been developed by the Covenant of Mayors Europe Office in collaboration with the Joint Research center -JRC[5]. MyCovenant is accessible from the Covenant of Mayors website or via mycovenant.eumayors.eu. To log in, municipalities need to use the email and password which received during registration stage. The step-by-step reporting and monitoring process for all Covenant signatories is presented in **Fig. 1** below[6]:

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[3] https://www.globalcovenantofmayors.org/who-we-are/

[4] https://iclei.org/gcom/

[5] https://commission.europa.eu/about-european-commission/departments-and-executive-agencies/joint-research-centre_en

[6] Reporting Guidelines, CoM, March 2020. Accessed from: https://eu-mayors.ec.europa.eu/sites/default/files/2022-10/Covenant-reporting-guidelines-EN-final.pdf

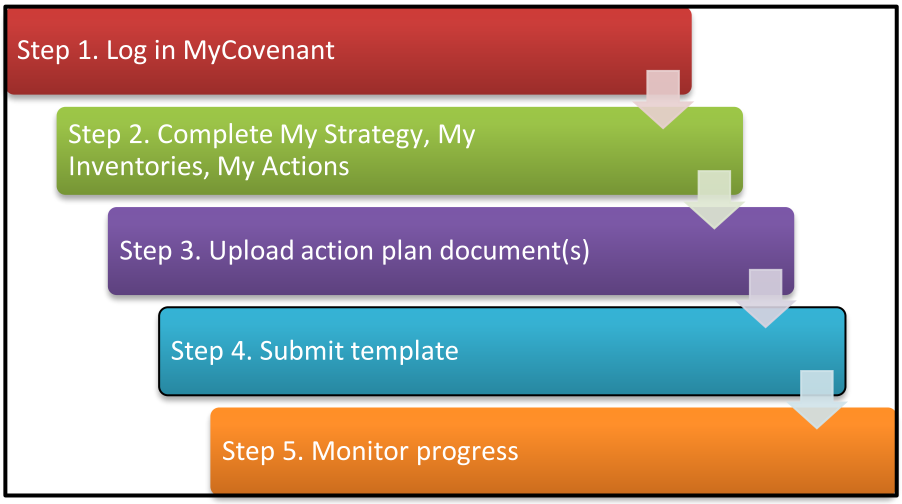

Fig. 1. Step by Step Reporting

The sections My Strategy, My Inventories, My Actions are the core of the Covenant reporting and monitoring framework. MyCovenant must be completed in English only. When the respective reporting sections of MyCovenant (Step 2) are completed and the action plan document(s) (Step 3) are uploaded, it is possible to submit action plan to the Covenant of Mayors.

All documents should be uploaded in a pdf format, in the national language, unless an English translation is available. The uploading of at least one action plan document (e.g. mitigation action plan/adaptation action plan/integrated mitigation and adaptation action plan) is mandatory. This plan(s) shall be duly approved by the municipal council or equivalent decision-making body. The upload of additional documents is optional.
In order to ensure that the submitted action plans align with the Covenant principles, the JRC carries out an assessment of the action plans submitted in MyCovenant. The analysis is guided by a set of eligibility criteria, provided below. Unless these criteria are met, the action plan will not be accepted. In all cases JRC, carries out an assessment of the plan and provides a feedback report with recommendations for improvement of the action plan. The feedback report is shared with each signatory through a certified e-mail system within six months of submission.

Eligibility criteria – the minimum requirements are[7]:

- The action plan must be approved by the Municipal Council or an equivalent body.

[7] Reporting Guidelines, CoM, March 2020. Accessed from: https://eu-mayors.ec.europa.eu/sites/default/files/2022-10/Covenant-reporting-guidelines-EN-final.pdf

- The action plan must clearly specify the Covenant mitigation target (i.e. at least 40% CO2 emission reduction by 2030) and adaptation goal.
- The action plan must be based on and include the results of a comprehensive Baseline Emission Inventory (BEI) and Climate Risk & Vulnerability Assessment (RVA).
- MyCovenant must be completed correctly, and the data reported must be coherent and complete.
- The BEI must cover the key sectors of activity (at least three out of four key sectors).
  - For mitigation, the action plan must cover the key sectors of activity (Municipal buildings, Tertiary buildings, Residential buildings and Transport) (at least two out of three selected key sectors), including, at least 3 key actions.
- The RVA must identify the most relevant climate hazards and vulnerable sectors
  - For adaptation, the action plan must include a set of actions, including, at least 3 key actions.

The action plan must be submitted within two years following the adhesion date, i.e. the date when the Municipal Council (or equivalent decision-making body) formally decided to join the Covenant of Mayors. In practical terms, this means that you need to complete the following sections of MyCovenant: (i) My strategy, (ii) Emission inventory, (iii) Risks & vulnerabilities, (iv) My Actions and upload the officially adopted action plan.

2.2 Common Reporting Framework (CRF)

GCoM Common Reporting Framework (CRF), allows for cities across the world to use one standardized approach to sharing information on their climate activities. It guides GCoM cities in assessing their greenhouse gas emissions, climate change risks and vulnerabilities, as well as planning and reporting in an integrated and coherent way.

CRF outlines the requirements and timeframes for each of the steps a city takes under the initiative. It specifies [8]:

1) which elements have to be covered by a city-wide greenhouse gas (GHG) emissions inventory
2) which aspects must be covered by a city-wide Climate Risk and Vulnerability Assessment

[8] Explanatory Note accompanying the Global Covenant of Mayors Common Reporting Framework, Guidance Note, GCoM, April 2019. Accessed from https://www.globalcovenantofmayors.org/wp-content/uploads/2019/04/Data-TWG_Reporting-Framework_GUIDANCE-NOTE.pdf

3) which requirements have to be met when setting city-wide emissions reduction targets, adaptation/climate resilience goals and access to secure, affordable and sustainable energy goals
4) which information has to be contained in climate action plans (covering the 3 GCoM pillars, i.e. mitigation, adaptation, energy access) adopted by GCoM cities
5) and what and how often cities must report under the initiative

Submission of reports are done through one of the two officially recognized reporting platforms:

- CDP and ICLEI's unified reporting system[9]
- the SECAP reporting platform, available in MyCovenant (the European Covenant Extranet)[10]

Cities only need to report once. Both reporting platforms reflect the GCoM CRF and the submitted data is shared with GCoM.

Each of the platforms has aligned with the GCoM framework and allows cities and local governments to report on the GCoM requirements and their progress. Cities are required to update any relevant information related to[11]:

- Basic information about the signatory (population, location, mayor, etc.)
- The target(s) and goal(s) set under the initiative
- GHG emissions in the sectors covered by the GCoM and a summary of the main methodological information related to the inventory (see chapter 3 for a detailed description of the requirements)
- The main results of the climate risk and vulnerability assessment
- A summary of the action plan, including a description of key actions

CDP-ICLEI provides feedback and recommendations on how the reported data can be improved and cities have the chance to amend their response based on this feedback. CDP-ICLEI validation process for GCoM signatories is shown in **Fig. 2**.

9 https://www.cdp.net/en/cities
10 https://mycovenant.eumayors.eu/signatory-registration
11 Explanatory Note accompanying the Global Covenant of Mayors Common Reporting Framework, Guidance Note, GCoM, April 2019. Accessed from https://www.globalcovenantofmayors.org/wp-content/uploads/2019/04/Data-TWG_Reporting-Framework_GUIDANCE-NOTE.pdf

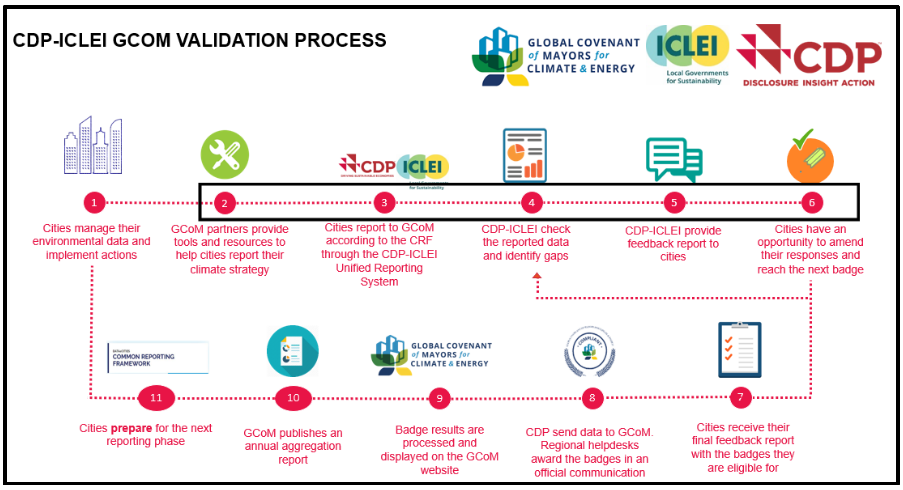

Fig. 2. CDP-ICLEI GCOM Validation Process[12]

3 SECAP Structure and Process

Signatories of the Covenant of Mayors commit to submitting a Sustainable Energy and Climate Action Plan (SECAP) within two years of joining the initiative. The SECAP serves to translate political commitment into tangible measures and projects. The development of a SECAP is not a linear process, and some steps may overlap with others. **Table 1** provides the phases of the SECAP process and the key elements for elaborating and implementing a successful SECAP.

Table 1. Phases of SECAP Process

PHASE	STEPS
Commencement	Political commitment and signing of the Cove-nant Involvement of municipal departments required Building support from stakeholders
SECAP preparation phase	Assessment of the current situation Establishment of the vision Elaboration of the SECAP SECAP approval and submission
Implementation phase	Implementation of mitigation and adaptation actions
Monitoring and reporting phase	Monitoring Reporting and submission of the monitoring report Review

[12] https://www.globalcovenantofmayors.org/

The Commencement phase marks the beginning of the journey towards the 2030 target. It involves the political commitment to the target and the adhesion to the Covenant of Mayors, as well as the involvement of all stakeholders in order to plan a coherent and integrated vision for the target year. This phase also includes the adaptation of the municipal structure to address the changes required for the SECAP elaboration and implementation.

In the Preparation phase, the evaluation of existing mitigation and adaptation measures is essential. A comprehensive strategy and action plan must be developed to reach the desired objectives. Once these have been determined, they must be documented in a plan that is submitted for approval by the municipal council/assembly.

The Implementation phase of this project seeks to create a low carbon and resilient environment for citizens, providing a healthier, more sustainable lifestyle. By reducing carbon emissions and increasing resilience to climate-related events, it will help to ensure a better quality of life for all.

In the Monitoring and Reporting phase, progress is tracked and evaluated, and any necessary adjustments to strategies and actions are made to ensure that the desired outcomes are achieved.

In order to mitigate the effects of climate change, the SECAP document should clearly outline the emission reduction target by 2030 (and potentially beyond), specifying the Baseline Emission Inventory (BEI) year and the type of reduction target (absolute reduction or per capita reduction). Additionally, the SECAP should include a number of adaptation goals that are coherent with the identified vulnerabilities, risks and hazards. Furthermore, the SECAP should outline the organizational structures created/assigned and the capacity of local administration, the involvement of stakeholders, the budget allocated for implementation and financing sources, and the implementation and monitoring process.

The baseline/reference year is the year used as a point of comparison for the inventory year. The number of inhabitants in the inventory year should be specified. The emission factors approach should be outlined, as well as the emission reporting unit (CO_2 or CO_2-equivalent). The responsible body/department (main contact) should be identified. Detailed BEI results should be provided in terms of final energy consumption and GHG emissions. If relevant, the inclusion of optional sectors and sources should be specified, as well as any assumptions made, references or tools used.

The local authority or region is expected to experience a variety of weather and climate events that could have a significant impact on the area. These events could include extreme weather such as floods, droughts, heatwaves, and storms. It is important to understand the vulnerabilities of the local authority or region to anticipate and prepare for these events. Climate change is expected to have a range of impacts on the local authority or region. These could include changes in temperature, precipitation, and sea level, as well as increased frequency and intensity of extreme weather events. It is important to identify the assets and people at risk from these impacts in order to develop strategies to protect them. By understanding the expected weather and climate events, vulnerabilities, and climate impacts in the local authority or region, it is possible to develop effective strategies to reduce the risks posed by climate change.

In order to ensure that adaptation actions and measures are effective, they must be coherent with the outcomes of the city risk and vulnerability assessment (RVA). The RVA should provide a comprehensive understanding of the risks and vulnerabilities of the city, and the adaptation actions and measures should be tailored to address these risks and vulnerabilities. The adaptation actions and measures should also be tailored to the specific context of the city, taking into account its unique characteristics and needs. This will ensure that the adaptation actions and measures are effective and appropriate for the city.

Mitigation actions and measures to reduce the impacts of climate change include increasing energy efficiency and transitioning to renewable energy sources. Increasing energy efficiency can be achieved through improved building design, energy-efficient appliances, and better insulation. Transitioning to renewable energy sources such as solar, wind, and geothermal can reduce emissions and provide clean, renewable energy. By taking these actions and measures, local administrations can reduce the impacts of climate change and create a more sustainable future.

Turkish local authorities are advised to follow the recommended structure when preparing their SECAPs, with the following content[13]:

1. SECAP executive summary

2. Targets and vision

- Commitments both for mitigation and adaptation

– For mitigation, the SECAP document should clearly indicate the emission reduction target by 2030 (and possibly beyond) clearly stating the BEI year and the reduction target type (absolute reduction or per capita reduction)
– For adaptation, the SECAP should include a certain number of adaptation goals, coherent with the identified vulnerabilities, risks and hazards.
– Organizational structures created/assigned and capacity of local administration
– Involvement of stakeholders
– Budget allocated for implementation and financing sources,

[13] Rivas, S., El-Guindy, R., Palermo, V., Kona, A. and Bertoldi, P., Guidebook: How to develop a Sustainable Energy and Climate Action Plan (SECAP) in the MENA Region, European Commission, Ispra, 2018, JRC113188.

– Implementation and monitoring process

3. Baseline Emission Inventory (BEI) and sectors

- Baseline/reference year
- Number of inhabitants in the inventory year
- Emission factors approach
- Emission reporting unit (CO_2 or CO_2-equivalent)
- Responsible body/department (main contact)
- Detailed BEI results in terms of final energy consumption and GHG emissions
- If relevant, also specify:

– Inclusion of optional sectors and sources
– Assumptions made, references or tools used

4. Climate Change Risk and Vulnerability Assessment (RVA)

- Expected weather and climate events particularly relevant for the local authority or region
- Vulnerabilities of the local authority or region
- Expected climate impacts in the local authority or region
- Assets and people at risk from climate change impacts

5. Mitigation actions and measures. For each measure/action, specify (whenever possible):

- Description,
- Department, person and/or company in charge of the implementation
- Timeline (start, end, major milestones),
- Cost estimation (Investment and running costs),
- Estimated energy savings and/or increased renewable energy production by target year (MWh/year),
- Estimated CO2 reduction by target year (tonnes/year)
- Indicators for monitoring

6. Adaptation actions and measures. The actions should be coherent with outcomes of the city risk and vulnerability assessment (RVA). For each measure/action, specify (whenever possible):

- Sector
- Description
- Responsible body/department/ and contact point
- Timing (end-start, major milestones)
- Stakeholders involved/advisory group
- Impacts, vulnerabilities and risks foreseen
- Costs
- Indicators for monitoring

7. **Energy poverty.** Actions to provide citizens access to secure, affordable, and sustainable energy.

4 Benefits Achieved Out of SECAPs

The Covenant signatories pledge to implement policy and undertake measure to reduce greenhouse gas (GHG) emissions, prepare for climate impacts, increase sustainable energy access and track progress towards these objectives.

The SECAP process provides organizations with the tools and resources necessary to build their institutional capacity and data management capabilities, while also increasing their understanding of energy efficiency and renewable energy solutions. This process helps organizations to identify and implement strategies that will reduce their energy consumption and carbon emissions, while also increasing their sustainability and resilience. By utilizing the SECAP process, organizations can reduce their energy costs, improve their environmental performance, and create a more sustainable future. Additionally, it highlights the need to invest in the area of climate action in order to promote protection of the environment, quality of life particularly in the areas of water, waste management and air pollution, climate change adaptation and mitigation including disaster risk reduction, and the development towards a resource-efficient, low-carbon and climate-resilient economy.

On a global level, SECAPs contribute to UN Sustainable Development Goals (SDGs) as presented in **Fig. 3**.

Fig. 3. SDGs Contributed by SECAPs

From a local perspective, SECAPs supports the areas provided in **Fig. 4**. The most important added-value has been identified as designing high quality bankable projects and bundle small-scale projects in larger investment packages that are more attractive for international financing institutions and commercial banks. With the SECAPs prepared and adopted, local administrations can get support from the governments and donors to develop innovative financing schemes, to involve private investors and catalyse private investments by stakeholders on their territories.

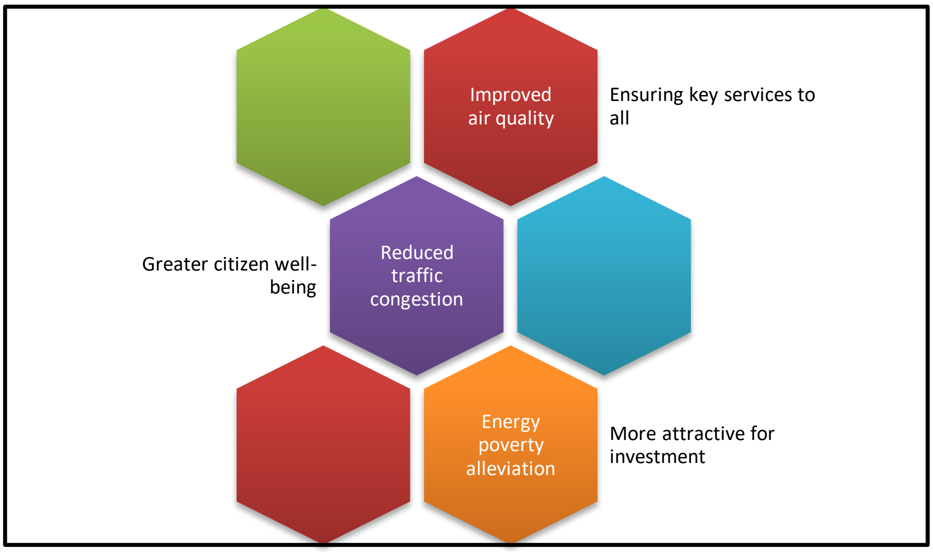

Fig. 4. Benefits of Climate Actions Identified by SECAPs

5 Challenges in Preparing SECAPs

Preparing SECAPs (Sustainable Energy and Climate Action Plans) can be a complex and challenging process. Preparing SECAPs requires significant resources, including personnel, data, and technology. Local administrations should ensure that these resources are available and adequate. SECAPs must be comprehensive, covering all aspects of energy efficiency and renewable energy. Many stakeholders must be consulted, and all relevant data must be gathered. SECAPs must include clear, measurable goals that are achievable and realistic. Securing funding for the implementation of SECAPs can be a challenge, as many governments and businesses may not be willing to invest in energy efficiency and climate adaptation actions.

From Turkish local administration perspective, it has been noticed that the SECAP development process is characterised by the following key challenges:

- The lack of multi-level governance between city departments has led to coordination challenges, resulting in a poor development of an integrated plan across different sectors and departments. This lack of coordination has hindered the development of an effective and efficient plan that would benefit the city as a whole.
- Municipal staff have shown a lack of engagement and interest in the project, which has hindered progress and made it difficult to move forward. It is essential that municipal staff become more involved and invested in the project in order to ensure its success.
- Despite having a clear vision for the city, the lack the knowledge and understanding of how to effectively engage key stakeholders and mobilize action across the city's geographical boundaries must be overcome to find ways to bridge the gaps between stakeholders and create a unified approach to achieving goals.
- Municipalities need a comprehensive data system to track energy consumption and other related data for multiple sectors, including municipal buildings and facilities, street lighting, municipal vehicles, and waste and wastewater. Such a system would provide valuable insights into energy consumption patterns and help municipalities to identify areas for improvement and cost savings. Additionally, it would enable municipalities to make more informed decisions about energy usage and to develop strategies for reducing energy consumption.
- The lack of efficient monitoring and appropriate fine tuning of the plan, coupled with the absence of an administrative unit to follow and/or implement the plan, may hinder the success of SECAP.
- Due to a lack of financial resources, it is not possible to implement the proposed SECAP measures. Without the necessary funds, the measures cannot be put into practice and the desired outcomes cannot be achieved.
- Municipal infrastructures are the primary focus of key actions. The city is not taking responsibility for the implementation of the plan.

6 Conclusion and Key Steps Forward

The Sustainable Energy and Climate Action Plan (SECAP) is an instrument that provides a comprehensive action plan for local governments to reduce their greenhouse gas emissions and transition to a low-carbon economy. SECAP outlines the steps that municipalities should take to reduce their emissions, including energy efficiency, renewable energy, and climate-friendly transportation. It also provides guidance on how to develop and implement sustainable energy and climate action plans, as well as how to monitor and report progress. Implementing SECAP, Turkish municipalities can help to reduce their emissions and contribute to a more sustainable future.

Turkish municipalities need to consider the following points while elaborating their SECAPs:

- Securing the high-level management's support for the SECAP implementation
- Ensuring that the SECAP is tailored to the municipality's needs and objectives
- Defining the scope of the SECAP clearly, including the timeline and budget
- Including a comprehensive review of current energy usage and associated costs
- Identifying potential energy efficiency measures and renewable energy options
- Developing a plan to track and monitor energy usage and progress towards targets

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Modeling of Degradation Kinetics in Photovoltaic Modules under Damp Heat Testing

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Abstract. Photovoltaic (PV) system installations have grown significantly in recent years reaching almost 1 TW capacity worldwide; however, reliability and durability of PV modules and module materials during real-world service have to be ensured for safe and long-term operation. Encapsulant polymers have a critical role in PV modules as they provide optical coupling, mechanical stability, electrical insulation, and most importantly protection for solar cells and cell metallization against environmental factors. Ethylene-vinyl acetate (EVA) is the most widely used encapsulant polymer, but it is prone to hydrolysis forming acetic acid as a degradation byproduct which leads to corrosion of the cell metallization and delamination issues resulting in performance loss and reduced service lifetime. In the Solar ERA.Net project, PV40+, we aim to develop modules with at least 40 years of service lifetime with the use of glass/glass construction with alternative encapsulant polymers such as polyolefin elastomer (POE) and thermoplastic olefin (TPO) in order to minimize humidity driven degradation mechanisms. Due to lack of acetic acid formation and higher volume resistivity against potential induced degradation (PID), these encapsulants are expected to perform better than EVA. As the first step, test modules will be manufactured and exposed to extended weathering testing under the damp heat conditions (85°C/85%RH) for up to 5000 hours with longitudinal power data collection. In this work, we present an empirical kinetic modeling approach in order to determine the activation energies of damp-heat driven degradation in power performance. This modeling consists of non-linear exponential curve fitting technique with reduced standard errors. Once the activation energies are determined, they can be used to estimate the equivalent damp heat testing times for various locations for a targeted service lifetime of 40 years.

Keywords: PV modules; degradation; reliability; service lifetime.

1 Introduction

Photovoltaic (PV) solar energy as a renewable energy resource has gained a significant attention in the last decade, reaching a total installed capacity of approximately 1 TW worldwide [1]. Ensuring the durability and reliability of PV modules and systems is of vital importance for maintaining the power generation capability throughout their lifetime. Currently, PV modules comes with 25 to 30 years of power performance guarantee; however, PV modules are exposed to various real-world climatic conditions such as ultraviolet (UV) radiation, heat, humidity, and mechanical stresses, during outdoor deployment for extended durations and experience degradation and failure. Depending on the module construction and stress factors, various degradation mechanisms such as delamination, potential induced degradation (PID), corrosion of the cell metallization, yellowing of the encapsulant, and embrittlement of the backsheet layer are reported to be occur in the field, causing performance loss [2].

A typical module construction, as shown in Fig. 1, consists of a glass frontsheet and a polymeric multi-layer backsheet, a polymeric encapsulant film, and an aluminum frame in order to protect solar cells from environmental stress factors and to provide electrical insulation for safety purposes. Choosing the right materials (and thus material combinations) is key to maximizing the durability and reliability of PV modules.

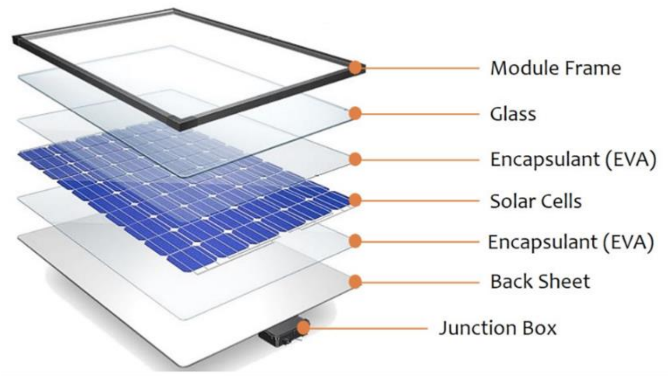

Fig. 1. A typical c-Si module construction with EVA encapsulants [3].

Encapsulant films are of critical importance as they provide adhesion between the front and back surface, optical coupling, mechanical stability, electrical insulation, and protection against environmental factors for solar cells and cell metallization [4]. In the commercial crystalline silicon (c-Si) PV modules, ethylene vinyl-acetate (EVA) is the most commonly used encapsulant material; however, it is vulnerable to hydrolysis and releases acetic acid as a degradation by-product, which leads to corrosion of the cell metallization, consequently reducing the power performance. In addition, modules with EVA encapsulants experience potential-induced degradation (PID) due to EVA’s low volume resistivity. Moreover, yellowing and delamination are also common issues reported in the fielded modules. Therefore, recent studies are directed toward the search for alternative encapsulant materials that can overcome the problems associated with EVA. Polyolefin elastomer (POE) and thermoplastic olefin (TPO) based encapsulants are gaining great attention as promising candidates [4].

In the Solar ERA.NET project, PV40+, it is aimed to develop modules with a service lifetime of at least 40 years by replacing EVA with alternative encapsulant films such as POE and TPO, and by using a double glass module architecture in order to minimize the moisture ingress into module construction. These alternative encapsulants are expected to outperform EVA due to the absence of acetic acid formation and their higher volume resistivity against PID.

The effect of heat and humidity is one of the most important stressors for PV modules in outdoor real-world conditions (and also used as a standard test protocol, as known as “damp heat”, in the IEC 61215 standard [5] in order to determine the ability of modules to withstand the effects of long-term penetration of humidity). Modules in the damp heat test are exposed to a temperature of 85°C and a relative humidity level (RH) of 85% for 1000 hours. Although this standard is designed to serve as a quality control procedure against manufacturing flaws for premature failures in the field, it is haphazardly translated as a reliability test for a service lifetime estimation. However, it is still a good indicator of the degradation mechanisms observed in real-world conditions, specifically for the degradation in power performance as a result of the degradation of polymeric encapsulant materials and corrosion of cell metallization elements.

2 Empirical Kinetic Modeling Approach

Koehl et.al. [6] has developed a methodology for estimating the equivalent damp heat testing time for a targeted service lifetime. In their study, several modules were degraded under the damp heat conditions at various temperatures and the activation energies of damp heat driven power degradation were derived using the well-known Arrhenius relationship. Then, translation of real-world climate conditions in terms of constant damp heat conditions were performed by treating effective humidity as a dose. First, the frequency distribution of 85%RH as a function of the module temperature at a given location was determined, and then, the calculation of the acceleration factors based on the activation energies of power degradation was performed. However, the calculation of the activation energies using the Arrhenius relationship requires exposures performed at least three temperatures, which is costly and time-consuming.

In this study, the modeling procedure applied in Kaaya et.al. [7] has been adapted instead with which the activation energies of the power degradation can be extracted without the need for multiple exposure conditions. Degradation rate (k_H) function for the hydrolytic degradation is as follows:

$$k_H = A_H \cdot rh_{eff}^n \cdot \exp\left(-\frac{E_H}{k_B T_m}\right) \tag{1}$$

where rh_{eff} is the effective module relative humidity (RH, %), n is a model parameter that indicates the impact of RH on power, E_H is the activation energy of the degradation process (eV), k_B is the Boltzmann constant (eV/K), and T_m is the module temperature (K). Using this degradation rate function, the following power degradation function is applied in order to predict the model output:

$$\frac{P_{MPP}(t)}{P_{MPP}(0)} = 1 - \exp\left(-\left(\frac{B}{k_i t}\right)^{\mu}\right) \tag{2}$$

where $P_{MPP}(t)$ and $P_{MPP}(0)$ are the module output power at time t and 0, respectively, k_i is the degradation rate constant of degradation process of i, which is, in our case, the degradation rate (k_H) for hydrolytic degradation, μ is the shape parameter, determining the shape of the degradation profile, and B is the power susceptibility (a material property, also a shape parameter), determining the differences in different module constructions). If the same kind of modules is studied, this B parameter can be set to 1.

After the model parameters are extracted, the time-to-failure (t_f) values can be calculated for the 20% loss in power performance as follows:

$$t_f = \frac{B}{k_i \cdot [|\log(0.2)|]^{\frac{1}{\mu}}} \tag{3}$$

In this approach, the power degradation function can be modelled using the non-linear exponential regression curve fitting technique and the estimation of the activation energies of the degradation processes, degradation rates, and time-to-failure values under the defined accelerated exposure conditions can be realized. In the study by Kaaya et.al. [7], the power degradation model is trained at one exposure condition for calibration and tested at another exposure condition for validation; however, the standard errors for the extracted model parameters are found to be quite large. This is because there are five coefficients in the model that need to be extracted, and due to the nature of non-linear exponential curve fitting approach, it leads to over-parameterization problem.

In the current study, the iterative prediction of the coefficients has been applied to have acceptable levels of standard errors and thus increase the confidence levels in the extracted coefficients. This new approach has eluded the need for multiple exposure conditions that are required for training and testing purposes.

3 Experimental

Since the manufacturing and testing of the newly designed modules is an ongoing process, no power degradation data is yet available for modeling, but once the manufacturing step is completed, extended weathering testing will be applied under the damp heat conditions (85°C/85%RH) for up to 5000 hours with current-voltage (IV) curve measurements every 500 hours. Therefore, the data reported in Koehl et.al. [6] will be used here instead for demonstration purposes. In this study, the durability of four different commercial PV modules with a glass/EVA/backsheet construction were exposed to damp heat conditions at a constant relative humidity level of 85 %RH, but at varying temperatures of 75°C for up to 8750 hours, 85°C for up to 5000 hours, and 90°C for up to 3250 hours. Modules were labeled as A, B, C, and D. Even though all the modules had the same lamination configuration, they showed different degradation profiles due to different components used by different manufacturers. Using the Arrhenius relationship, the activation energies were found to be 0.56 eV, 0.71 eV, 0.66 eV, and 0.64 eV for modules A, B, C, and D, respectively. Here, only the analysis results for the module D will be presented as a case study as it showed the most pronounced degradation among other modules.

4 Results

Fig. 2 shows the modeling results for the module D calibrated at 85°C and validated at 75°C and 90°C. It is to be noted that information about the module type and exposure conditions are given by the plot title and the estimated activation energies and model metrics such as the R-squared values are given inside the plot. While points represent the observed data, dashed lines represent the predicted data by the model. Shaded areas represent the 95% confidence intervals.

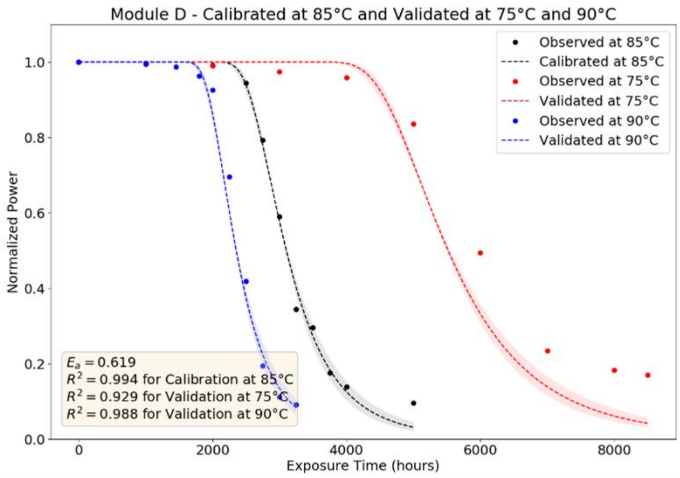

Fig. 2. Modeling results for the module D.

It can be seen that the parameters estimated using the calibration data have led to successful predictions of the validation data. Almost all models have R-squared values of greater than 0.90. Here, in the plot, the model calibration has been performed only on the temperature of 85°C and model validation has been performed on the temperatures of 75°C and 90°C. When each of these temperatures was used for the calibration model, similar validation model fits were obtained with similar parameter estimates. The respective plots are not included here, but the estimated parameters can be seen in Table 1.

Table 1. Extracted model coefficients for the module D at various temperatures.

Module	Temperature	E_H	μ	n	A_H	B	t_f
	75 °C	0.62	4.77	1.39	419.4	1.21	5999.3
D	85 °C	0.62	6.46	1.40	420.0	1.20	3098.9
	90 °C	0.64	5.95	1.28	335.8	0.29	2403.6

Fig. 3 shows the respective Arrhenius diagram constructed using the time-to-failure values calculated using the parameter estimated by the calibration model and the resulting the resulting acceleration factors have been plotted against the corresponding inverse temperature values. It can be seen that the activation energy of the power degradation calculated using the Arrhenius relationships have been found to be in line with the one estimated using the calibration model.

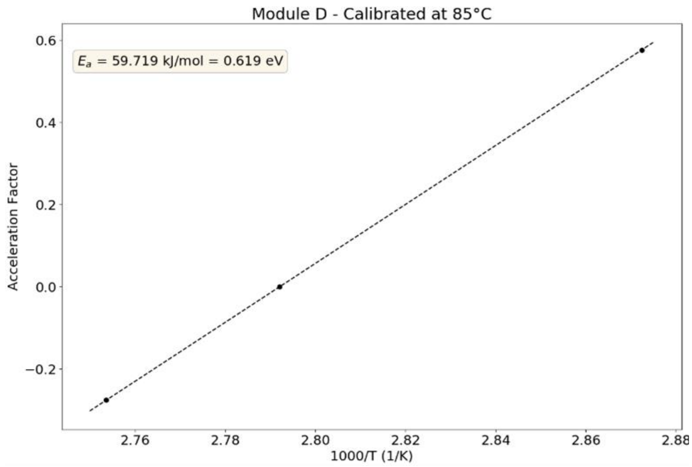

Fig. 3. The respective Arrhenius diagram for the module D.

Here, the initial estimates and boundary conditions for the regression model have been optimized only for the module D; however, model optimization should be module-specific. Setting all the initial estimates and the boundary conditions the same for all module types in the non-linear exponential curve fitting can lead to poor estimation of the model parameters. Since modules constructed with different encapsulants are expected to have different degradation profiles under the applied exposure conditions, each module has to be treated individually, and thus, the parameters have to be optimized separately for each module type.

5 Conclusions

The effect of heat and humidity is one of the most important stress factors for the service lifetime of PV modules (also used as a standard test protocol, known as “damp heat”, in the IEC 61215 standard). In this study, the non-linear exponential curve fitting has been shown to be an effective technique for extracting activation energies of damp heat driven power degradation without the need for applying costly and time-consuming multiple exposure conditions. The extracted activation energies can be used to calculate the equivalent damp heat testing times for a targeted, i.e., 40 years, service lifetime at any given location for determining climate-sensitive degradation of PV modules.

Acknowledgements

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The Effect of Local Climate Conditions on the Service Lifetime of Photovoltaic Modules

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Abstract. Photovoltaic (PV) system installations have grown remarkably in recent years; however, service lifetime issues during real-world operation need to be tackled. Polymeric components in PV modules, specially encapsulants, are susceptible to hydrolysis resulting in failures such as cell metallization corrosion and leading to power loss and reduced service lifetime. The standard certification test (IEC 61215) applied to PV modules is designed to determine the manufacturing flaws and premature failures; however, it is haphazardly correlated to service lifetime prediction. The damp heat exposure (85°C/85%RH for 1000 hours) is one of the required protocols within this standard to assess the impacts of long-term ingress of humidity into the module structure; however, its validity as a potential reliability test is often disputed by the PV community. In this work, a methodology for determining equivalent damp heat testing times for 30 years of service lifetime is demonstrated for Turkey and the results are presented as a country map. The analysis clearly shows that equivalent damp heat testing times vary markedly depending on the local climatic conditions and the activation energy of the power degradation. This study underlines the importance of (1) the module structure since it is associated with the activation energy of the degradation processes and (2) climatic conditions since it is related to the effective environmental stressors impacting the modules' lifetime during real-world operation.

Keywords: PV modules; standard testing; degradation; service lifetime

1 Introduction

Photovoltaic (PV) system installations have increased tremendously in the last decade mostly thanks to technological and market developments for which increased cell/module efficiencies and reduced manufacturing and electricity costs are the main drivers. However, for sustainable growth, increasing durability and reliability of PV modules is of great importance for increasing service lifetime. In today's market, PV modules typically come with a 30-years of power performance warranty (i.e., %20 power loss at the end of life), but the problem is that the same warranty applies to all PV modules installed in all climatic conditions. During real-world service, PV modules experience various environmental conditions such as heat, humidity, ultraviolet light, and mechanical stresses due to heavy snow loads, gusty winds, or hail. Choosing the right materials (and thus material combinations) for module lamination is of significant importance for increasing the durability and reliability of PV modules. As the service lifetime of PV modules are sensitive to climatic conditions, recent studies are directed toward the material-dependent and climate-induced degradation mechanisms and failure modes [1].

A commercial crystalline silicon (c-Si) PV module construction typically consists of a front glass sheet, solar cells with metallization elements, laminated between two layers of encapsulant polymers, a polymeric backsheet, a junction box, and a frame. The packaging polymers, such as the encapsulant and backsheet films, mainly provide electrical insulation, environmental protection, and mechanical stability to the solar cells and cell metallization. Ethylene-vinyl acetate (EVA) is the most common encapsulant; however, it is prone to hydrolysis, which leads to corrosion of the cell metallization, resulting in reduced power performance and thus decreased service lifetime [2].

The current service lifetime warranties are often granted by module manufacturers based on the IEC 61215 standard [3]; however, this standard basically determines the design qualification of PV modules for long-term operation. It is useful to identify the premature failures that might occur due to design, processing, and manufacturing flaws, but should not be seen as a reliability test for service lifetime estimation. As stated by the standard, the actual service lifetime depends on the module construction as well as on the climatic conditions under which the PV modules are installed. Damp heat exposure is one of the required protocols within this standard in order to determine the effects of long-term penetration of humidity into the module construction. According to this protocol, PV modules are aged under the constant temperature of 85 C and relative humidity (RH) level of 85% for 1000 hours. Unfortunately, when PV modules pass this with certain criteria, it is, without any obvious reason, translated as a service lifetime. Considering the complexity of the real-world conditions and the complexity of the PV module construction, the standard’s capability of forecasting long-term performance is a source of vigorous discussion in the PV community [4].

In this study, mapping of equivalent damp heat testing times for Turkey was realized in order to reveal the risks associated with the application of one specific set of conditions for a certain amount of time for all kinds of module constructions and climatic conditions for service lifetime prediction.

2 Modeling Approach

2.1 Calculation of the Equivalent Damp Heat Testing Times

Koehl et. al.[5-6] has developed a methodology for calculating equivalent testing time for a targeted service lifetime depending on the activation energy of the power degradation based on humidity driven reactions during damp heat testing. In this work, the same methodology was applied to investigate the differences between climate conditions in Turkey and their effects on the equivalent damp heat testing times. The analysis steps, as reported in Koehl et. al. [5-6], are as follows:

1. Calculation of the module temperature by the Faiman Model [7]:

$$T_{mod} = T_{amb} + \frac{G_{POA}}{U_0 + U_1 \cdot WS} \tag{1}$$

where T_{amb} and T_{mod} are the ambient air and module temperatures (°C), respectively, G_{POA} is the plane or array irradiance (W/m^2), U_0 is the constant heat transfer coefficient (taken as 25 W/m^{2}K), U_1 is the convective heat transfer coefficient (taken as 6.84 W/m^{3}sK), and WS is the wind speed (m/s).

2. Calculation of the surface relative humidity at module surface and module temperature (micro-climate) according to the following expression:

$$RH(T_{mod}) = RH(T_{amb}) \times \frac{p_{sat}(T_{amb})}{p_{sat}(T_{mod})} \tag{2}$$

where $RH(T_{mod})$ and $RH(T_{amb})$ are the relative humidity (%) at the module surface and the module temperature and at the ambient air temperature, respectively, and $p_{sat}(T_{mod})$ and $p_{sat}(T_{amb})$ are the water vapor saturation pressures at the module temperature and ambient air temperature, respectively.

3. Calculation of the effective surface relative humidity at module surface and module temperature (sigmoidal model) according to the following expression:

$$RH_{eff} = \frac{1}{[1 + 98 \times \exp(-9.4 \cdot RH(T_{mod}))]} \tag{3}$$

4. Calculation of the time periods (Δt_{85}) for 85 %RH as a function of module temperature (T_{mod}) according to the following expression:

$$\Delta t_{85}(85\%RH, T_{mod}) = \Delta t_{mon} \times \frac{RH_{eff}}{0.85} \tag{4}$$

where Δt_{mon} is the monitored time interval in which the effective humidity levels that are determined will be transferred to a contribution of the time period of high humidity levels (usually 85% RH for standard module testing).

5. Performing the time transformation to the constant test temperature and integration according to the following expression in order to calculate equivalent testing time for a given service lifetime:

$$\Delta t_{ref} = \sum_1^N \Delta t_i \cdot \exp\left[\left(-\frac{E_a}{R}\right)\left(\frac{1}{T_i} - \frac{1}{T_{ref}}\right)\right] \tag{5}$$

where Δt_{ref} is the time period in the reference (standard) test conditions, Δt_i is the time interval, E_a is the activation energy of the damp heat driven power degradation processes, T_i is the transient temperature at time intervals of Δt_i, and T_{ref} is the reference (standard) temperature of 85 °C. The calculated testing time (Δt_{ref}) is then multiplied by the number of years targeted as the design service lifetime, i.e., 30 years. Here, the activation energy is free, unknown parameter.

This methodology can be seen as a translation of real-world climate conditions in terms of constant damp heat conditions, treating effective humidity as a dose, and basically follows the determination of the frequency distribution of 85%RH as a function of the module temperature at a given location and then the calculation of the acceleration factors based on the activation energies of power degradation processes. Koehl et. al. [5-6] have demonstrated their procedure by taking four different relative humidity models into account, namely ambient relative humidity, surface relative humidity (micro-climate model), squared surface relative humidity (squared micro-climate model as hydrolysis kinetics of polymeric materials suggest second order kinetics with water content), and effective surface relative humidity (sigmoidal model) for some selected locations across different climate zones in the world.

2.2 Data Preparation

In order to obtain point locations in Turkey, typical meteorological year (TMY) data were acquired from the Photovoltaic Geographical Information System (PVGIS) [8] database with 0.05 resolution in both latitude and longitude that corresponds to 5.5 km and 4.3 km in real-scale, respectively. This resolution is the highest offered by the PVGIS database, ensuring precise spatial representation of the data, summing up to a total of 43,000 coordinate numbers for Turkey. This TMY data contains hourly data of global horizontal irradiance (GHI), direct normal irradiance (DNI), diffuse horizontal irradiance (DHI), air pressure, dry-bulb temperature (air temperature), wind speed and wind direction (degrees clockwise from north), relative humidity, and long-wave downwelling infrared radiation.

For each point location, TMY data was initially requested from the PVGIS database and subsequently examined for any potential corrupt or missing values. If no issues were found, the process was carried out in accordance with the analysis workflow: (1) evaluation of the frequency distribution of 85% relative humidity as a function of the module temperature, and (2) calculation of the equivalent damp heat testing times for 30 years of service lifetime based on varying activation energies. The resulting dataset consists of three columns: longitude, latitude, and equivalent testing time.

2.3 Mapping Procedure

To visualize the data for mapping purposes, Kernel Density Estimation (KDE) was applied by using geoplot [9] which is a high-level Python geospatial plotting library. KDE is a non-parametric statistical technique used to estimate the underlying distribution of a dataset, allowing one to visualize and analyze the data's distribution without making any assumptions about its specific form [10]. The dataset containing latitude, longitude, and equivalent testing time was further processed to make it suitable for KDE analysis. As KDE operates with point objects and forms kernels based on object count, numbers of point objects were first generated, corresponding to the equivalent testing time value, using latitude and longitude values to represent the geographical coordinates effectively. Then, at a given specific location, duplication of coordinate point objects per equivalent testing time value was performed. After these preprocessing processes, visualization involved plotting a KDE heatmap. This heatmap illustrates the density of points on a map. To enhance the presentation, an Albers Equal Area projection was applied, along with specific settings for figure size, value threshold, legend, and clipping to confine the plot's boundaries according to Turkey's shapefile [11]. Once these parameters were configured, the map was generated.

3 Results

3.1 Frequency Distributions and Equivalent Damp Heat Testing Times

In order to demonstrate the analysis workflow for a point location, Istanbul is given here as an example for a moderate climate in Turkey. Fig.1 shows the frequency distribution of 85 %RH (in hours) as a function of module temperature (left) and the equivalent testing times at 85°C/85%RH for a service lifetime of 30 years as a function of activation energy (right) for various humidity models.

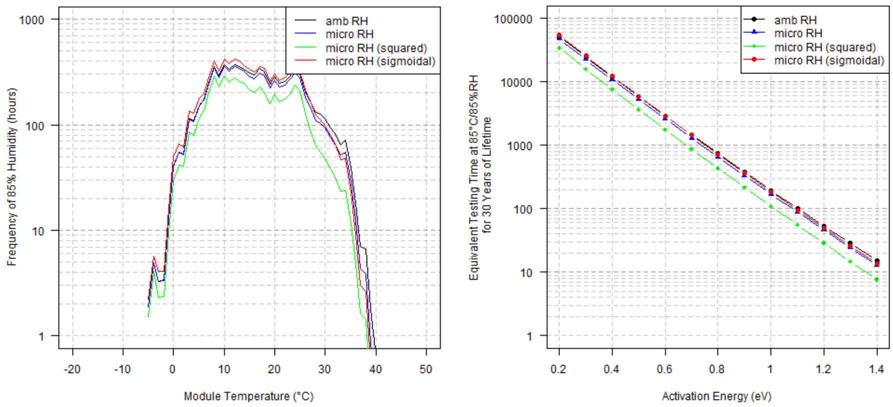

Fig.1. Frequency distribution of 85%RH (in hours) as a function of module temperature (left) and equivalent testing times at 85°C/85%RH for a service lifetime of 30 years as a function of activation energy (right) for Istanbul.

It can be noticed that the maximum frequency distribution is centered around the module temperature of 10-30 °C, and depending on the activation energies of power degradation, equivalent damp heat testing times vary tremendously. When investigating the different geographical regions within the country, frequency distributions of 85 %RH are seen to differ in dry and humid climates, but the details will be a subject of another publication.

Table 1 provides the equivalent damp heat testing times at 85°C/85%RH for a service lifetime of 30 years in five cities across Turkey as a function of activation energy for the effective surface relative humidity (sigmoidal) model. Since the humidity levels are high in humid climates, the equivalent testing times are also higher compared to dry climates. For example, for an activation energy of 0.6 eV, while only 1047 hours of testing is sufficient to represent 30 years of lifetime in Konya, 2913 hours of exposure is required for the same lifetime in Istanbul. The same situation is true for Ankara and Antalya: while only 1100 hours of testing is sufficient to represent 30 years of lifetime in Ankara, 2220 hours of exposure is required for the same lifetime in Antalya. Even though Trabzon has more rainfall than Istanbul, it is seen that Istanbul requires more testing time due to higher humidity and temperature conditions as these factors affect module temperature and micro-climate conditions at the module surface.

Table 1. Equivalent damp heat testing times at 85°C/85%RH for a service lifetime of 30 years in selected cities as a function of activation energy (for the sigmoidal model).

E_a (eV)	Ankara	Antalya	Istanbul	Konya	Trabzon
0.3	12607.8	19576.7	25540.7	12111.0	23233.3
0.4	5512.3	9363.3	12249.9	5271.6	10748.7
0.5	2445.2	4531.7	5941.3	2331.3	5035.0
0.6	1100.8	2219.6	2913.1	1047.4	2387.1
0.7	503.0	1100.2	1443.4	478.0	1145.0
0.8	233.3	551.8	722.4	221.5	555.4
0.9	109.9	280.0	365.0	104.2	272.3

3.2 Equivalent Damp Heat Testing Times Map of Turkey

Equivalent damp heat testing times map of Turkey is shown in Fig. 2, representing the required hours under standard damp heat conditions (85°C and 85%RH) for 30 year of service lifetime. Since the activation energies for power degradation in PV modules due to humidity driven reactions under the damp heat conditions are reported in Koehl et. al. [5-6] to be in the range of 0.5 to 0.7 eV for standard glass/backsheet modules with EVA-based encapsulants, an average activation energy of 0.6 eV was selected here for the mapping purposes. Also, only the results for the sigmoidal humidity model were demonstrated as it was shown to provide the best fit for the estimation of the degradation impact of the effective surface humidity.

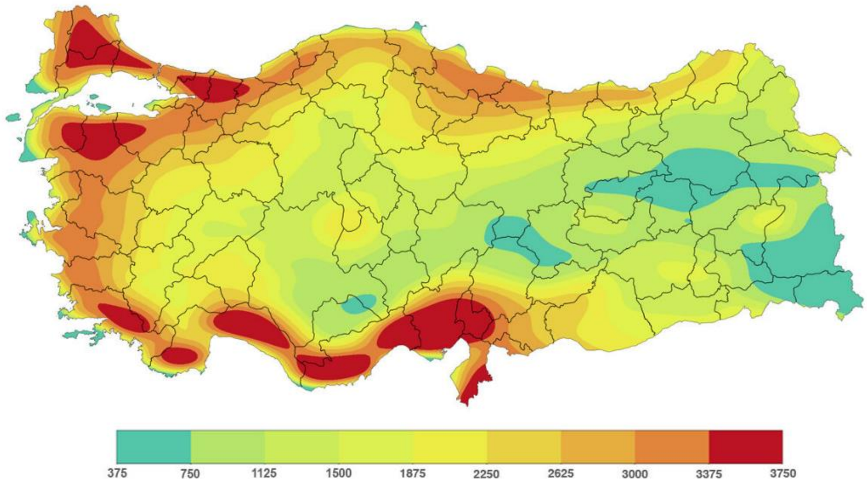

Fig. 2. Equivalent damp heat testing times map of Turkey for 30 years of service lifetime (with an activation energy of 0.6 eV for power degradation).

Due to high levels of relative humidity in the coastal areas (i.e., hot and humid climate), these regions require longer hours of testing times for a targeted service lifetime than the interior regions (i.e., hot/cold and dry climate). This is particularly true for the Western, Southern, and Northwestern regions. Normally, the coastal areas in the Northern region would be expected to have higher testing times as well, but the diminished temperature values in this region seem to lead to lower testing times. The mid-Eastern and the Southeastern regions have the lowest testing times in the county as expected from the dry climate conditions.

It is seen that the equivalent testing times for 30 years of service lifetime depends strongly on the location as local climate conditions, specifically air temperature and relative humidity, can vary substantially, even in the same (relatively small) country. While the testing time is around 2900 hours in the city of Istanbul for an activation energy of 0.6 eV, it reduces to around 365 hours for an activation energy of 0.9 eV (i.e., double glass module construction with an edge seal with reduced humidity ingress), indicating that the standard testing time of 1000 hours will not be adequate for representing 30 years of lifetime for the former and will be redundant and excessive for the latter. These testing times will also change if the targeted service lifetime is extended beyond the current standard of 30 years.

4 Conclusions

In this study, equivalent damp heat testing times for 30 years of service lifetime of PV modules has been calculated for Turkey with 0.05 resolution in both latitude and longitude and the results were presented as a country map. The results indicated the risks associated with the use of standard testing for service lifetime prediction for all kinds of module constructions and climatic conditions. It was shown that both the module construction, as it is directly related to kinetics of the degradation processes, and the climatic conditions, as it is directly related to the effective stress factors, are of utmost importance, influencing the modules' lifetime during real-world service. Mapping the equivalent damp heat testing times helped point out the changes in climatic conditions, and hence, stress factors, even in the same country, and their effect on the required damp heat testing times for a targeted service lifetime of PV modules. Instead of country maps, further study will include a worldwide map with varying activation energies for different module constructions and targeted service lifetimes.

Acknowledgements

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Extending Photovoltaic Power Plant Service Lifetime: Module Design Innovations and Implications for Environmental Impact

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Abstract. This study examines the ReCiPe midpoint environmental impacts associated with extending the service lifetime photovoltaic (PV) modules from 30 to 40 years. The investigation considers a scenario in which the reduction of degradation rates is facilitated by an innovative PV module design involving alternative encapsulant materials for the lamination process. Drawing upon existing research that quantifies PV module failure and its contributing factors, the lamination process is identified as a crucial component in enhancing the reliability and durability of the module during real-world operation, ultimately enabling their use for an extended service lifetime. A lifecycle assessment is conducted for both 30-year and 40-year scenarios to evaluate the trade-offs in environmental impacts between the increased output from the power plant and alterations in the project requirements, such as encapsulation material and energy inputs for module production, as well as maintenance and repairs during the prolonged service lifetime. The preliminary results underscore the significant contributions of the manufacturing of solar cells and modules to environmental impacts, suggesting that efficient strategies to augment the modules' service lifetime seem to be promising for reducing the overall environmental impacts of PV modules. According to the initial findings, extending the power plant's service lifetime can lead to considerable improvements in various environmental impact categories, including an 18% reduction in metal depletion, a 20% reduction in terrestrial acidification and a 23% decrease in global warming potential. This study highlights the importance of refining PV module technology, specifically through innovations in module design for lamination process, to increase service lifetime and substantially mitigate environmental impacts, ultimately fostering a more sustainable future for renewable energy.

Keywords: PV modules; reliability; service lifetime; lifecycle assessment

1 Introduction

Photovoltaic (PV) modules are a crucial component in the global renewable energy transition. However, degradation and failures, particularly those related to the lamination process, can significantly impact their performance and lifespan. This study aims to assess the potential benefits of a new lamination process for PV modules through life cycle assessment (LCA). Focusing on the role of lamination in maintaining PV module functionality and efficiency throughout their service lifetime, the trade-off between the increased output and the possible extra resource usage due to the innovative production process, mainly due to alternative encapsulation materials, and maintenance requirements in the extended service lifetime is modeled using LCA.

Numerous studies have employed LCA to analyze the environmental impacts of PV energy production systems. These studies mostly emphasize the need for up-to-date LCA data to assess country-specific electricity mixes, allocation procedures, continuous improvements in PV systems, and their environmental impacts. Jungbluth et al. [1] highlight the importance of considering country-specific electricity mixes in LCA studies by analyzing twelve grid-connected PV systems in Switzerland. Stoppato [2] identifies critical stages in multi-crystalline silicon (mc-Si) module production. Dones and Frischknecht [3] compare mono-crystalline (sc-Si) and multi-crystalline (mc-Si) silicon cell technologies and observe that high electricity requirements determine most of the environmental burdens of current PV systems. Fthenakis et al. [4] argue that outdated data and imbalanced assumptions in publications overestimate external environmental costs of PV systems compared to other energy systems. Sherwani et al. [5] review LCA studies on PV-based electricity production systems, including various PV module production technologies and they underline the needs for ongoing improvements of mono-crystalline (sc-Si) PV systems and of environmental performance evaluations.

The literature on analyzing reasons for and quantifying PV module degradation and failures highlights the significance of PV module degradation mechanisms and rates and the impact of climatic zones on these rates for targeting improvements in module design and assessing potential gains from longevity and performance. Li & Lv [6] found that metallization and interconnect corrosion were one of the most common failure modes with an average degradation rate of 0.73%/year. Yedidi et al. [7] found that backsheet delamination was the primary safety issue in frameless PV modules with encapsulant browning and thermo-mechanical solder bond fatigue being the primary degradation mechanisms. Köntges et al. [8] provided a comprehensive review of PV module failures, targeting PV module designers, industry professionals, and standardization committees. Gallardo-Saavedra et al. [9] analyzed quantitative data from 63 PV power plants, and regarding the module component level failures, they found out that discoloration of the encapsulant, glass breakage, potential-induced degradation (PID), snail trails, and backsheet failures are the most common degradation mechanisms. Kumar and Sarkar [10] sought to improve conventional reliability models by incorporating environmental impacts. Ali et al. [11] discussed the importance of failure rate basics for grid-connected PV systems. Jordan et al. [12] analyzed and reviewed the extensive PV field reliability literature and they found that degradation percentages decreased in newer installations deployed after 2000 with delamination being more frequent in hot and humid climates.

Cell metallization corrosion, not only limited to hot and humid climates, has been identified as one of the critical factors in PV module reliability, emphasizing the importance of encapsulants used and lamination processes. Ethylene-vinyl acetate

(EVA) is the most widely used encapsulant polymer, but it is susceptible to hydrolytic degradation, forming acetic acid as a byproduct, which then leads to corrosion of the cell metallization and delamination issues resulting in performance loss and reduced service lifetime [13,14]. Therefore, recent years have seen increased interest in alternative materials for encapsulation in module lamination, aiming to improve the durability and reliability and thus to increase the service lifetime of PV modules while reducing environmental impacts. Studies explore various aspects of encapsulation materials and degradation analysis, revealing the potential benefits and drawbacks of alternative materials. Various encapsulation materials, such as polyolefin elastomer (POE), thermoplastic olefin (TPO), and ionomers, have been studied under different stress factors [15-17] for improved resistance to degradation.

In the Solar-ERA.NET project, PV40+, a new module design is proposed by replacing EVA with alternative encapsulant films such as POE and TPO, and by using a double glass module architecture in order to minimize the humidity ingress into module construction with the aim of having a service lifetime of at least 40 years. These alternative encapsulants are expected to outperform EVA due to the absence of acetic acid formation and their higher volume resistivity against PID. In this study, the effect of increasing the service lifetime of a typical commercial PV module from 30 to 40 years is investigated in terms of environmental impacts with a special focus on global warming potential, metal depletion, and terrestrial acidification.

2 Methodology

This study employs a cradle-to-grave life cycle assessment (LCA) for a 570 kWp ground-mounted PV electricity generation facility, evaluating the environmental impacts associated with the production of 1 kWh of electricity. The LCA encompasses all stages of the PV power plant's lifecycle, including raw material extraction, transportation, production, assembly, operation, maintenance, and end-of-life waste management and recycling processes. A Type-A decision context is deemed appropriate, with the functional unit being the generation of 1 kWh of electrical energy. Lifecycle inventories (LCI) are obtained from the Ecoinvent database (v3.7) [18], the LCA study reports by the International Energy Agency’s (IEA) Photovoltaic Power Systems Programme (PVPS) [19], and Swiss Federal Office of Energy [20]. The system boundaries encompass the production of components, facility construction, assembly, electricity generation, facility maintenance, and end-of-life processes.

An LCI modeling framework based on economic allocation to average processes is adopted in this study. The assessment does not focus on regionalized evaluations but assumes that 16.1% of the European solar cell mix is supplied by the production facilities located in Turkey. The lifecycle impact assessment (LCIA) is conducted using the ReCiPe Midpoint method with a focus on impact categories such as global warming (kg CO_2-eq/kWh), terrestrial acidification (kg SO_2-eq/kWh), and metal depletion (kg Fe-eq/kWh). These categories are particularly important in the context of PV systems due to the most common environmental concerns and the amounts of metal used in the electrical installation, module frames, and mounting system components.

In this study, the lifecycle inventory for mono-crystalline module production was adapted from Frischknecht et al. [19] and compared with alternative encapsulant materials such as POE and TPO instead of the current standard EVA. The updated inventory showed higher water and electricity consumption but a more economical process in terms of other material inputs compared to Jungbluth et al. [20]. An average standard of 200Wp/m^2 with mono-crystalline as the module type was assumed for the peak module performance, as mono-crystalline modules dominate the commercial installations with 85% market share and efficiency rates of above 20%.

Owing to developments in cell and module architectures, an increase in overall performance under all solar radiation conditions throughout the year has been observed. Consequently, the annual average output increased by about 15% from 1287 kWh/kWp/year [20] to 1471 kWh/kWp/year [19] for Turkey. Then, in a 570 kWp project based on current standards, accounting for 3% repair and rejections, 2940 m^2 of modules would be supplied, and 2850 m^2 would be actively used. For the lifecycle inventory, adjustments were made proportional to reduced module requirement, and accordingly for mounting structures, electrical cable installations. Inverter installation was based on peak output and remained as fixed as in the 570 kWp inventory in Frischknecht et al. [19]. Energy usage and transportation inputs for commissioning of the PV power plant were adjusted based on the total mass of the supplied inputs.

Lifecycle inventories for the 30-year PV power plant considered as a base case in this study. The inventory for the mono-crystalline PV module used in the project is presented in Table A1 in the Appendix. The environmental impact analysis is considered an average case for Turkey, selecting the Turkish (TR) market for provider regionalization when possible, and the European (RER) or global market (GLO) otherwise. The impact results for a 570 kWp PV facility with mono-crystalline modules to be operated for 30 years in Turkey are presented in Table A2 in the Appendix.

Efficient use of modules is crucial due to their environmental impact, especially solar cells contribute significantly to global warming potential. Therefore, it is critical to ensure a long lifespan for the modules to reduce lifecycle impacts. An improved lamination process with alternative encapsulant materials can increase the durability and reliability for long-term operation by preventing or slowing down performance degradation over years. This enables extended and more efficient operation of PV power plants, yielding higher energy output from the scarce resources used for plant commissioning. An alternative lamination process can therefore lead to reduced environmental impacts with higher efficiency and longevity. Based on this, a 40-year service lifetime is considered as an initial target, which represents a potential 33% increase in electricity generation and a significant reduction in environmental impacts. We adopted a 0.5% annual linear degradation rate as proposed by Jordan et al. [12] and assumed that this extends for the additional 10 years. Preferring the moderate linear rate to the two-stage degradation (i.e., stable at first and fast decline or vice versa) implies that the devised lamination process provides better protection against sudden encapsulation-related degradations that might well happen with the modules with EVA encapsulates.

In the 40-year scenario, the total energy output of the plant is 30% higher than that of a 30-year project when module degradation continues linearly between years 30 and 40. However, increased energy use in module manufacturing, and the need for repair and replacement of modules, inverters, cables, and mounting system structures during the extended service life may lead to an unexpected change in the overall environmental impact. To examine the balance between the increased input requirements in these areas and the energy output provided by the project's lifetime, the increased needs in these areas for a 40-year plant project scenario must be included.

For encapsulant material alternatives, such as POE and TPO, designed for lamination, there is no need for higher temperature or pressure than the current standard EVA process. Nevertheless, a 5% increase in diesel and electricity requirements can be considered for the entire module production process inventory, including lamination, to account for processes requiring higher processing temperatures or longer pressure applications. The impact of changing materials from EVA to alternatives is negligible, as indicated by the case results with polyethylene (PE) as shown in Table A3 in the Appendix. Here, PE is used as a proxy material for POE and TPO. Mounting/transportation systems, are made of robust materials with a 60-year service lifetime [19], may occasionally fail and require repair or replacement, but the failure rate is either negligible [21] or very small compared to other failure modes [22]. Therefore, no increase in requirements is considered for a 40-year project in terms of mounting/transportation systems. Inverters are assumed to have a 15-year service life [20], yet inverters with a capacity of 500 kW are built on a large chassis, providing easy access and maintenance [19]. With regular maintenance and repair, and assuming an additional 10% load for each 15-year inverter supply, the equipment is sustained until the end of the 40th year. For cables, the 30-year mark is critical [20]; after 30 years, cables need to be thoroughly examined and replaced, or a completely new electrical installation is required. However, the excess service lifetime of electric installation is considered to be outside the boundary of the LCA and thus a 33% increase in electrical installation load seems to be reasonable for the purpose of this initial iteration of LCA.

3 Preliminary Results and Conclusions

The results, as shown in Fig.1, indicate that extending the service lifetime of PV modules to 40 years through the use of enhanced lamination provides a reduction of around 20% in lifecycle impacts for the vast majority of ReCiPe midpoint impact categories. Note that some of the impact categories are eliminated from Fig.1 due to small scale and limited space. It can be seen that there is an 18% reduction in metal depletion, a 20% reduction in terrestrial acidification, and a 23% reduction in global warming potential. The use of alternative encapsulant materials, replacing EVA, and thus lamination processes, has negligible effects on these impacts as the environmental burden due to manufacturing of solar cells still dominates the overall picture.

This study demonstrates the potential benefits of an innovative lamination process with alternative encapsulation materials for PV modules through lifecycle assessment. A 40-year project scenario, compared to a 30-year one, showed significant reductions in environmental impacts. These promising results indicate that extending the service lifetime of PV power plants and employing innovative lamination processes can significantly contribute to the sustainable future of PV electricity generation. However, further research should be conducted, including sensitivity analysis for optimistic and pessimistic cases to account for potential technological developments in equipment and maintenance, as well as possible challenges in the extended service lifetime.

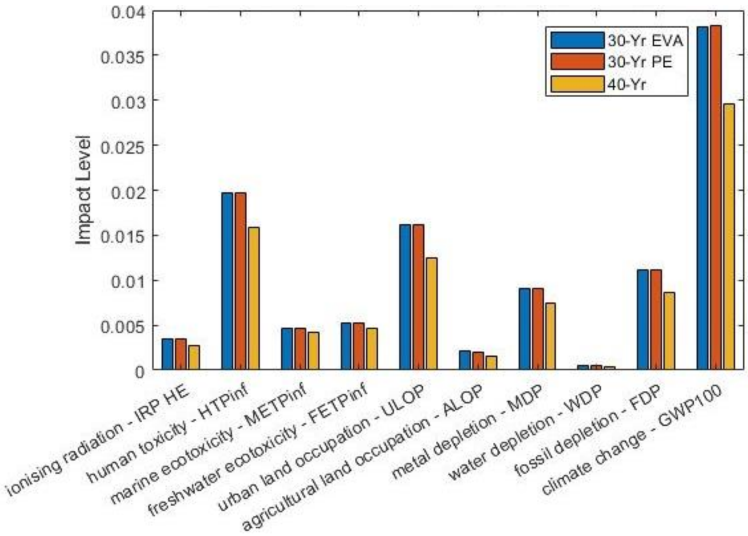

Fig. 1. ReCiPe Midpoint impact results for 30-year 570 kWp PV power plants with EVA and PE laminated modules and a 40-year 570 kWp PV power plant.

Appendix

Table 1. Reference flows for constructing a 570 kWp open-ground PV power plant for 30 years.

Inputs	**Amount**	**Unit**
Inverter 500kW	2.28	item(s)
Modules for 570kWp	2940	m^2
Photovoltaic mounting system for 570kWp	2850	m^2
Electric installation for 570kWp	1×0.907	unit
Diesel, burned in building machine	7670×0.907	MJ
Electricity, low voltage	36×0.907	kWh
Transport, lorry, 7.5-16 metric ton, fleet average	8540×0.977	t×km
Treatment, sc-Si PV module	38808	kg
Outputs	**Amount**	**Unit**
Open-ground PV power plant 570kWp	1	item(s)
Heat, waste	130×0.907	MJ

Table 2. Reference flows for 1 m^2 laminated PV module. Note that EVA laminated module data modified from [19] and the module with the alternative encapsulation is approximated by PE. Negative values represent waste treatment input flows presented together with waste outputs.

Inputs	**EVA Module**	**PE Module**	**Unit**
1-propanol	0.0159	0.0159	kg
Aluminum alloy, AlMg3	2.13	2.13	kg
Copper, cathode	0.103	0.103	kg
Corrugated board box	0.763	0.763	kg
Diesel, burned in building machine	0.00875	0.00875	MJ
Diode, auxiliaries and energy use	0.00281	0.00281	kg
Electricity, medium voltage	14	14	kWh
Ethylene-vinyl acetate, foil	0.875	0	kg
Polyethylene high density, granulate	0	0.875	kg
EUR-flat pallet	0.05	0.05	item(s)
Glass fiber reinforced plastic, polyamide, injection molded	0.295	0.295	kg
Hydrogen fluoride	0.0624	0.0624	kg
Isopropanol	1.47×10^{-4}	1.47×10^{-4}	kg
Lead	7.25×10^{-4}	7.25×10^{-4}	kg
Lubricating oil	0.00161	0.00161	kg
Photovoltaic cell, single-Si wafer	0.935	0.935	m2
Photovoltaic panel factory	4.00×10^{-6}	4.00×10^{-6}	Item(s)
Polyethylene terephthalate, granulate	0.346	0.346	kg
Polyvinylfluoride, film	0.112	0.112	kg
Potassium hydroxide	0.0514	0.0514	kg
Silicone product	0.122	0.122	kg
Soap	0.0116	0.0116	kg
Solar glass, low-iron	8.81	8.81	kg
Tap water	5.03	5.03	kg
Tempering, flat glass	8.81	8.81	kg
Tin	0.0129	0.0129	kg
Transport, freight train	16.6	16.6	t×km
Transport, freight, lorry 16-32 metric ton,	2.77	2.77	t×km
Water	0.503	0.503	kg
Wire drawing, copper	0.103	0.103	kg
Outputs	**Amount**	**Unit**	

Photovoltaic panel, mono-Si	1	1	m^2
Heat, waste	50.3	-50.3	MJ
Carbon dioxide, fossil	0.0218	-0.0218	kg
NMVOC, non-methane volatile organics	0.00806	-0.00806	kg
Municipal solid waste	0.03	-0.03	kg
Waste incineration of municipal solid waste	-0.03	0.03	kg
Waste plastic, mixture	0.0281	-0.0281	kg
Waste incineration of plastics	-0.0281	0.0281	kg
Waste polyvinylfluoride	0.00429	-0.00429	kg
Waste incineration of plastics (rigid PVC)	-0.00429	0.00429	kg
Hazardous waste, for incineration	0.00161	-0.00161	kg
Wastewater, from residence	0.00453	-0.00453	m3

Table 3. Environmental impacts of 30-year 570 kWp open-ground PV power plants with EVA and PE laminated modules, and a 40-year 570 kWp open-ground PV power plant. Note that most ReCiPe Midpoint impact categories have a difference of 1/1000 or less between 30-year EVA and 30-year PE, and in all categories, except ozone depletion, the difference is less than 1%. The 27% difference in the ozone depletion should be considered due to the very low absolute magnitude. The 40-year project reduces impacts in most categories by around 20%. For freshwater ecotoxicity and marine ecotoxicity, 10% reduction is indicated. 18%, 20% and 23% reductions in metal depletion, acidification and global warming, respectively, are promising for a sustainable future of PV electricity generation.

Inputs	**30-yr EVA**	**30-yr PE**	**40-yr**	**Unit**
particulate matter formation	9.78×10^{-5}	9.80×10^{-5}	7.64×10^{-5}	kg PM10-eq
Ionizing radiation	0.00349	0.00348	0.00271	kg U235-eq
Human toxicity	0.01965	0.01967	0.01588	kg 1,4-DCB-eq
Marine ecotoxicity	0.00466	0.00467	0.00415	kg 1,4-DCB-eq
Freshwater ecotoxicity	0.00521	0.00521	0.00466	kg 1,4-DCB-eq
Photo-chemical oxidants	0.00014	0.00014	0.00011	kg NMVOC
Urban land occupation	0.01623	0.01623	0.0125	m^2a
Terrestrial ecotoxicity	5.68×10^{-5}	5.68×10^{-5}	4.38×10^{-5}	kg 1,4-DCB-eq
Terrestrial acidification	0.00015	0.00015	0.00012	kg SO_2-eq
Agricultural land occupation	0.00207	0.00206	0.0016	m^2a
Metal depletion	0.00905	0.00907	0.00746	kg Fe-eq
Water depletion	0.00046	0.00046	0.00035	m^3
Fossil depletion	0.01113	0.01112	0.00863	kg oil-eq
Freshwater eutrophication	2.11×10^{-5}	2.11×10^{-5}	1.67×10^{-5}	kg P-eq
Ozone depletion	3.67×10^{-9}	4.67×10^{-9}	2.83×10^{-9}	kg CFC-11-eq

Natural land transformation	6.15×10^{-6}	6.16×10^{-6}	4.80×10^{-6}	m^2
Marine eutrophication	4.69×10^{-5}	4.70×10^{-5}	3.65×10^{-5}	kg N-eq
Global warming potential	0.0382	0.03826	0.0296	kg CO_2-eq

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The Effect of Unique Properties and Attributes of a County on Urban Carbon Footprint Calculations: A Comparative Study

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Abstract. According to the Paris Agreement, local governments should initially be responsible for combating global warming. Hence, carbon footprint (CF) calculations of countries, cities, and districts are becoming more important. In CF studies, it has been observed that the climate is a significant factor due to the varying temperatures and energy required for residential heating and cooling loads. Turkey is divided into four heating zones, 1st zone being the warmest 4th being the coldest. This study involves Carbon Footprint (CF) calculations of two similar Turkish towns in different climate regions with similar population sizes, Seydikemer and Merzifon, being in the 1st heating zone and 3rd heating zone, respectively. The variation in the climate conditions has a major effect on stationary energy consumption and carbon emission levels. Using local heating degree days (HDD) and cooling degree days (CDD) values to compute heating and cooling loads is a practical method for calculating stationary energy usage. Seydikemer district, HDD, and CDD values are 767 and 773, respectively, whereas Merzifon district has HDD and CDD values of 2156 and 216, respectively. These HDD and CDD values suggest that the amount of energy consumption for heating purposes in Merzifon is significantly high, whereas energy consumption for cooling purposes in Seydikemer is considerably higher. This variation demonstrates the impact of HDD and CDD on carbon emissions very clearly. In this study, the CF of two towns has been evaluated and compared for each of five main sectors: stationary energy, transportation, wastes, industrial processes and product use, and agriculture, forestry, and other land use. In both counties, stationary energy has the largest share, approximately 65% in Seydikemer and 53% in Merzifon, excluding biogenic carbon emissions. Additionally, in Merzifon, the transportation sector has the second largest share, with approximately 34 %, since Merzifon has an airport and is on a major highway connecting big cities, whereas the transportation sector has only about 5 % share in Seydikemer. On the other hand, in Seydikemer, agriculture, forestry, and other land use sector has the second largest share with approximately 25 % since its economy relies primarily on agriculture, whereas this sector has only about 2 % share in Merzifon. Consequently, geographical location, economic activities, and the variation of weight in five sectors define the emission distribution, and each county's unique properties must be evaluated to mitigate the emission levels.
Keywords: Urban carbon footprint, Emission sources, Degree-days

1 Introduction

Each district has unique sustainability problems with their environment and resources, such as limiting greenhouse gas (GHG) emissions, wisely choosing energy and water supply and wellbeing of their citizens. International organizations developed guidelines and regulations to address these environmental problems aiming to reduce CO_2 emissions and mitigate the effects of climate change. A bold step taken forward is a legally binding international treaty on climate change, The Paris Agreement, adopted by 196 Parties (including Türkiye) at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015 [1]. According to the treaty, emissions need to be reduced by 45% by 2030 and reach net zero by 2050, to keep global warming under 1.5°C. Countries have been submitting national climate action plans since 2020, which include macro-scale commitments. However, identifying opportunities at the community level is crucial for effective implementation. The agreement also recognizes the role of cities, regions and local authorities in addressing climate change, to reduce emissions, build resilience and decrease vulnerability to support and encourage regional and international cooperation. Hence, implementation of these initiatives heavily relies of collective efforts from local governments, civil initiatives of counties, industries, and individuals.

Within this framework, The Intergovernmental Panel on Climate Change (IPCC) being the United Nations body for assessing the science related to climate change, assesses and reports the impacts, and possible responses to climate change caused by human activity. IPCC published, 2006 IPCC Guidelines for National Greenhouse Gas Inventories in order to provide a technically sound methodological basis of national greenhouse gas inventories. With the 2019 Refinement, the guidelines not only introduced scientific and other technical advances to tackle the problem but also updated default emission factors.

The 2006 IPCC Guidelines and the 2019 Refinement that followed were created with the purpose of helping countries calculate the amounts of greenhouse gases that are produced or removed as a result of human activities. To identify, track, and mitigate greenhouse gas emissions resulting from human activities, the most effective approach would be to focus on individuals, counties, neighborhoods, and households. Thus, it is essential to identify practical means of evaluating a municipality's environmental sustainability so that these endeavors can be implemented on a community level. The GPC (Global Protocol for Community-Scale Greenhouse Gas Inventories) provides cities and local governments with a reliable and internationally recognized framework for measuring, assessing, and disclosing their greenhouse gas emissions [2]. This framework is based on the guidelines set forth by the IPCC and is designed to provide transparent, consistent, and comprehensive greenhouse gas emission calculations, while clarifying ambiguities.

In various applications, it becomes apparent that there are a number of technical problems associated with greenhouse gas inventories for urban areas [3]. There are several potential benefits to having a meticulously organized and well-prepared inventory of greenhouse gas emissions. Having a methodology for creating an action plan that adheres to both mitigation and adaptation policies would be extremely valuable for the sustainability and GHG inventories of a city [4], [5].

This study is based on previous GHG calculations of two moderately sized Turkish counties, Seydikemer in 2017 and Merzifon in 2021 [6], [7]. Comparing the GHG emission levels of two cities in different climates based on stationary energy provides a valuable opportunity for analysis. Additionally, potential measures for mitigating future greenhouse gas emissions are recommended, taking into account the specific properties and attributes of the county.

2 Two Counties on Track to Net Zero Emissions: Seydikemer and Merzifon

Seydikemer and Merzifon with similar population size but different motivations, demanded detailed GHG emission calculations. Seydikemer is not only an exporter of agricultural product but also a region with natural and historical wonders with a considerable tourism potential. On the other hand, although agricultural products are important, industry and exports are of high importance to Merzifon. Merzifon has an airport, located on an important transit road, has a wastewater treatment facility. Seydikemer has a coast, located on an important transit road, has a limited wastewater treatment facility. Locations of the two districts is demonstrated in Figure 1 and information of these two districts can be seen in Table 1. The direct distance between two counties is approximately 700 km and both are in considerably different climatic conditions.

Fig. 1. Locations of the Two Districts. [8]

Table 1. Information of Two Districts

Name of the City	Seydikemer, Mugla	Merzifon, Amasya
Inventory Year	2017	2021
Population	61,000	74,727
Land Area	2,208 km^2	971 km^2
Altitude	211 m	740 m
Economy	Agriculture, livestock, tourism	Industries, exports, agriculture
Climate	Mediterranean climate, winters rainy not so cold, summers dry and hot	Affected by both black sea and continental climate, summers dry and not so hot,

		winters, fall and spring rain and snowfall, cold,
HDD	767	2,156
CDD	773	216

It is now widely recognized that any region wishing to become a major player in tourism or international trade must demonstrate its commitment to environmental protection, combatting global warming, preserving historical and archaeological treasures, and promoting sustainability by providing a detailed carbon footprint report for the region. The GPC method, also known as the 'Global Protocol for Communities GHG Emissions Inventories' provided by the C40 World Cities Initiative and the International Council of Local Environmental Initiatives (ICLEI), was used in GHG emissions studies. If, for any reason, a valid coefficient cannot be found for Turkey or a certain emission cannot be calculated due to the absence of emission factor/data, then EU values, if not, DEFRA, UK, USA values are used respectively. Initially, SWOT analysis was conducted for both municipalities employees to measure their knowledge about climate change and how well they knew the municipality they work in.

3 Methodology

The primary sources of carbon footprint are the daily activities of humans in their homes and workplaces, which contribute to greenhouse gas emissions. These activities include space heating and cooling, lighting, the use of home and office appliances, and transportation.

The carbon footprint of the two counties was evaluated using the updated Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC) methodology, which classifies GHG emissions from city activities into six main sectors:

- Stationary energy
- Transportation
- Waste
- Industrial processes and product use (IPPU)
- Agriculture, forestry, and other land use (AFOLU)
- Any other emissions occurring outside the geographic boundary because of city activities.

It is important to note that the GPC methodology provides clear definitions for scopes of city inventories. The GPC methodology defines three scopes for city inventories which are shown in Figure 2:

- Scope 1: GHG emissions from sources located within the city inventory boundary
- Scope 2: GHG emissions resulting from the use of grid-supplied electricity, heat, steam, and/or cooling within the city boundary

- Scope 3: All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

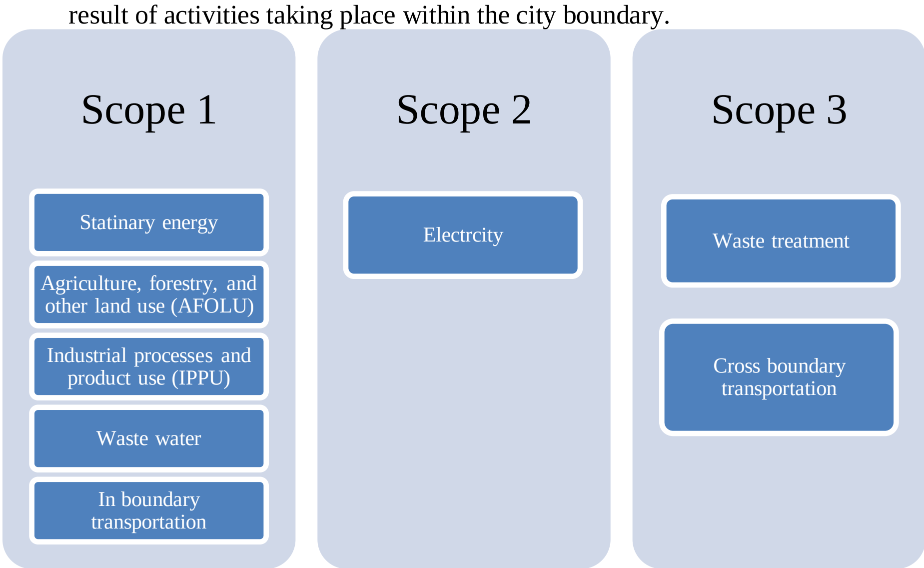

Fig. 2. Classification of GHG Emission in a City

The Figure 2 illustrates the inventory and city boundaries. According to the GPC, the reporting of greenhouse gas emissions must include the greenhouse gas type, scope, sector, and sub-sectors.

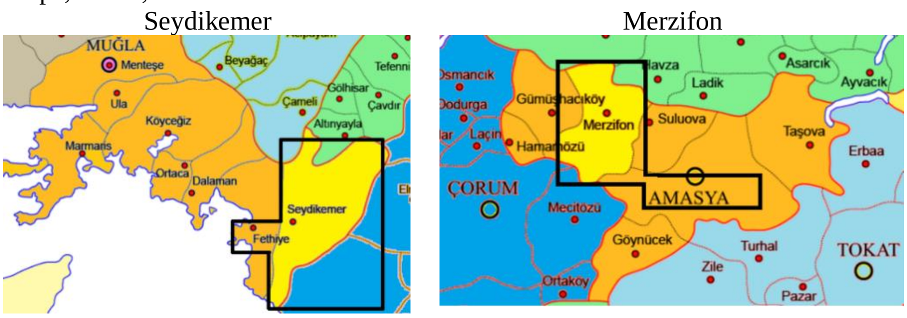

Fig. 3. The Inventory and City Boundaries of Seydikemer and Merzifon

The carbon footprint calculations showed that stationary energy is a significant source of emissions in both counties. Therefore, this study focuses on comparing emissions from stationary energy and waste between the two counties. Emissions from stationary energy sources are calculated by multiplying fuel consumption data (activity data) with the corresponding emission factors. The reliability of the activity data is crucial, and the following factors should be carefully considered:

- To ensure accurate calculation of emissions, it is important to obtain the distribution of fuel consumption by sub-sectors for each fuel type. The sales data for the stationary energy and transportation sectors should be evaluated separately to ensure reliable activity data.

- Identification of sampling methodology that represent actual consumption data.
- Determination of buildings distribution and energy consumption patterns that will form the basis of scaling factors.
- Modeling of energy consumption data as density in (GJ/m^2-year) and/or in similar units.
- Estimating total or incomplete consumption data that reflects actual energy usage.
- Scaling of known fuel consumption data on a provincial or national level can be achieved by using population and relevant indicators as basis for scaling factors.

To estimate greenhouse gas (GHG) emissions from most sources, cities will have to use an activity data and multiply it with a corresponding emission factor linked to the activity being measured (Equation 1). In particular, Equation 2 is used in GHG emission from electricity consumption calculation.

$$\text{GHG emissions} = \text{Activity data} \times \text{Emission factor} \quad (1)$$

$$GHG_{electricity} = C_{electricity} \text{ x } E_{electricity} \quad (2)$$

where:

- $GHG_{electricity}$ is the CO_2 emissions from electricity consumption of all economic sectors (tCO_2/year);

- $C_{electricity}$ is consumption of electricity of all sectors (MWh/year);

- $E_{electricity}$ is the is the emission factor (tCO_2/MWh)

The studies on both counties confirmed that, space heating and cooling has a considerable weight in stationary energy [9, 10, 11]. Electricity, natural gas and other energy consumption data also revealed a substantial potential for GHG emission reductions in stationary energy savings. Since, space heating and cooling mostly relies on climatic conditions, local heating degree days (HDD) and cooling degree days (CDD) values to compute heating and cooling loads is a practical method for calculating stationary energy usage.

Heating degree days (HDD) and cooling degree days (CDD) are commonly used metrics in building energy modeling and climate analysis to estimate the amount of energy required for heating and cooling buildings. HDD is a measure of the number of degrees that the outside temperature falls below a specific base temperature (15^{o}C) over a given period, typically a day, week, month, or heating season. CDD, on the other hand, is a measure of the number of degrees that the outside temperature rises above a specific base temperature over a given period. The base temperature (22^{o}C) for CDD is typically set at the temperature at which a building needs to be cooled to maintain a comfortable indoor temperature.

HDD and CDD data, are frequently used in building energy modeling and GHG inventory accounting to estimate energy consumption and GHG emissions associated with space heating and cooling [12, 13, 14]. The HDD and CDD values of a region can calculated by Equations 3 and 4 [15].

$$If\ T_m \leq 15\ ℃\quad Then\ [HDD = \sum_i (18\ ℃ - T_m^i)]\quad Else\quad [HDD = 0] \tag{3}$$
$$If\ T_m \geq 22\ ℃\quad Then\ [CDD = \sum_i (T_m^i - 21\ ℃)]\quad Else\quad [CDD = 0] \tag{4}$$

where T_m^i is the mean air temperature of day i.

4 Comparison of the Findings and Discussion

Greenhouse gas (GHG) emissions, as calculated using the GPC methodology, are affected by various factors beyond just population. The factors mentioned include climate, production choices, available energy sources, location, and facilities within the district. This means that the level of GHG emissions in a particular district is not solely dependent on the number of people living in it, but also on various other factors that can influence the amount of emissions.

For instance, a district with a cold climate may consume more energy for heating, resulting in higher GHG emissions. Similarly, the production choices made by industries or businesses in a district can impact emissions, as some production methods may be more energy-intensive than others. Availability of renewable energy sources, such as wind or solar power, can also affect emissions, as can the transportation choices and infrastructure in the district. Therefore, it is important to consider all these factors when designing policies or initiatives to reduce GHG emissions in a particular district.

This approach can help create more effective strategies that take into account the unique characteristics and challenges of each location. Table 2 demonstrates such variations, although having similar number of residential electricity subscribers, the details of stationary energy consumption data in two districts demonstrate considerable differences. In the inventory year, natural gas was not available in Seydikemer but on the other hand, fuel oil and coal consumption in residential buildings in the colder climate of Merzifon proves that, HDD-CDD values, fuel choices and availability are of great importance.

Table 2. Stationary Energy Consumption in Residential Buildings

	Seydikemer	Merzifon
Number of residential electricity subscribers	28,000	28,339
Electricity consumption in residences.	35,703,291 kWh	53,162,505 kWh
LPG consumption in residences	1,384 ton	759 ton
Fuel Oil consumption in residences	-	444 ton
Coal consumption in residences	2,520 ton	28,912 ton
Wood consumption in residences	13,437 ton	9,355 ton
Natural gas consumption in residences	-	23,973,618 m^3

In order to achieve significant reductions in stationary energy consumption and greenhouse gas emissions, it is essential to consider local factors such as consumption patterns and the varying properties of buildings in a district. The energy consumption patterns of old buildings can differ significantly from those of modern buildings due to differences in construction materials, insulation, and heating systems. Therefore, it is important to consider the mix of buildings in neighborhoods, while developing energy efficiency policies and programs. Tables 3, 4, 5 and 6 reveal a similar distribution between residential and public buildings in energy consumption pattern. These studies are based on a set of surveys, designed to gather detailed information of buildings in different neighborhoods, which was conducted by a team from the municipality.

Table 3. Stationary Energy Consumption in Institutional Buildings and Facilities

	Seydikemer	Merzifon
Number of public buildings electricity subscribers.	808	645
Electricity consumption in public buildings.	14,226,735 kWh	35.179,674 kWh
LPG consumption in public buildings	16 ton	10 ton
Fuel Oil consumption in public buildings	-	272 ton
Coal consumption in public buildings	220 ton	-
Diesel consumption in public buildings	-	246,280 L
Natural gas consumption in public buildings	-	2,674,636 m^3

Table 4. Stationary Energy Consumption in Commercial Buildings and Facilities

	Seydikemer	Merzifon
Number of commercial buildings electricity subscribers.	8.913	3.088
Electricity consumption in commercial buildings.	29,033,871 kWh	24,355,550 kWh
LPG consumption in commercial buildings	326 ton	106 ton
Coal consumption in commercial buildings	445 ton	3,158.ton
Wood consumption in commercial buildings	2,206 ton	5,514 ton
Natural gas consumption in commercial buildings	-	914.569 m^3
Olive-pomace oil consumption in commercial buildings	200 ton	-

Since the electricity consumption information (process and lighting and other infrastructure) of the industrial establishments in Merzifon Organized Industrial Zone is not given in detail, all of the original electricity consumption is included in the fixed energy in this report. By adding a note to the report, it was stated that it should be separated in the next report.

Table 5. Stationary Energy Consumption in Manufacturing and Construction Industry

	Seydikemer	Merzifon
Number of Manufacturing and construction industry electricity subscribers.	76	81
Electricity consumption in Manufacturing and construction industry.	9,808,382 kWh	60,648,032 kWh
LPG consumption in Manufacturing and construction industry	65 ton	12 ton
Coal consumption in Manufacturing and construction industry	150 ton	-
Wood consumption in Manufacturing and construction industry	150 ton	-
Natural gas consumption in Manufacturing and construction industry	-	2,777,966 m^3

Table 6. Stationary Energy Consumption in Agriculture Forestry and Fishing Industry

	Seydikemer	Merzifon
Number of agriculture forestry and fishing industry electricity subscribers.	3,693	484
Electricity consumption in agriculture forestry and fishing industry	10,592,157	9,976,076 kWh
Diesel consumption in agriculture forestry and fishing industry	8,000,000 L	3,300,000 L
LPG consumption in agriculture forestry and fishing industry	4.6 ton	-
Coal consumption in agriculture forestry and fishing industry	22,200 ton	-
Wood consumption in agriculture forestry and fishing industry	500 ton	-

Due to their distinct geographical locations and potential for renewable energy sources, the two district produce energy differently, with one district utilizing solar and hydro power and the other relying on wind power to generate electricity. Table 7 demonstrates the details of renewable energy production in the inventory year.

Table 7. Renewable Energy, Installed Power and Net Energy Production in the Inventory Year.

	Renewable Energy	Installed Power	Net Energy Production
Seydikemer	Hydro and Solar	121.4 MW	223,200,000 kWh
Merzifon	Wind	92.8 MW	255,968,086 kWh

In both countries, municipality collects solid waste, then it is transported to a neighboring county that has solid waste landfills where it is disposed of. Table 8 demonstrates the solid waste collected in the inventory year. The main differences between the districts are that, solid waste of Merzifon is partially converted into methane for electricity production and Merzifon has a proper wastewater treatment system.

Table 8. Sold Waste Generation in the Inventory Year

Seydikemer	Merzifon
12,500 ton/year	16,838 ton/year

Table 9 reveals that, methane production from the waste used in energy generation and wastewater treatment consequently affect GHG emissions. The table also emphasizes the varying weight of agriculture, forestry, and other land use (AFOLU) in Seydikemer versus industrial processes and product use (IPPU) in Merzifon.

Table 9. Emission Distribution by Sources

kg CO_2e	Seydikemer	Merzifon
Stationary energy	195,843,529	355,787,142
Transportation	14,824,983	226,381,412
Waste	64,847,840	19,125,140
Industrial processes and product use (IPPU)	15,027,632	54,901,200
Agriculture, forestry, and other land use (AFOLU)	240,429,019	102,975,645

While the emission distribution by scopes may not provide a detailed or complete picture of the situation, it does offer insight into the origins of major problems. Finally, Table 10 illustrates the emission that occur inside the city boundaries and imported / exported emissions.

Table 10. Emission Distribution by Scopes

kg CO_2e	Seydikemer	Merzifon
Scope 1 and 2	465,526,867	725,234,425
Scope 3	65,446,136	33,936,123
Total	530,973,003	759,170,548

5 Conclusion

In 2017, GHG emissions for Seydikemer is calculated to be 8.7 tons/person. 2021 GHG emissions for Merzifon is calculated to be 10.15 tons/person. These figures are 38% and 61% higher, respectively, than the 6.3 tons/person figure given by TURKSTAT for Turkey in 2020. It should be emphasized that TURKSTAT figure does not include agriculture, forestry and land use emissions.

While the use of refrigerants is expected to be higher in Seydikemer, the reason for the higher usage in Merzifon is due to some public institutions and the airport. Similarly, the effect of fuel oil usage is seen in some public institutions and public housing in Merzifon.

The adverse effects of GHG emissions on the climate, such as rising temperatures and more frequent extreme weather events, can lead to increased energy consumption for heating and cooling purposes, which in turn contributes to further GHG emissions. This creates a feedback loop that exacerbates the problem of climate change.

The number of residents or buildings alone are not enough to accurately predict the level of stationary energy consumption in a district. Other factors, such as the age and efficiency of buildings and appliances, local weather conditions, and the behavior of residents, also play a critical role. The team from the municipality conducted surveys to collect detailed information on buildings in different neighborhoods, forming the basis of these studies. In this Study, the data provided by energy companies has been initially verified and then used as such in calculations.

Understanding these variations in stationary energy consumption data is essential for developing effective energy efficiency policies and programs. By identifying the key factors that contribute to energy consumption in each district, policymakers and energy providers can develop tailored strategies that address the unique challenges and opportunities of each community. This approach can lead to significant reductions in energy use and greenhouse gas emissions, ultimately helping to mitigate the impacts of climate change.

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Carbon Footprint Analysis with the Emphasis of Neighborhood Emission Distribution: A Case Study of Merzifon District

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Abstract. According to the Paris Agreement, the responsibility of tackling global warming should start with local governments. With time running out, carrying out carbon footprint (CF) analysis on a local scale has become urgent. This study carries out the CF calculation of Merzifon District for the year 2021, which is located in the central north of Turkey, according to the Global Protocol for Community-scale Greenhouse Gas Emission Inventories (GPC). Merzifon, with its airport, ever-growing organized industrial site housing several industries leading in foreign exports in the sectors they are active, high-yielding agricultural land, and a population of over 74,000, has one of the oldest municipalities. As a result, 46.9% of total emissions, including biogenic emissions, are from stationary energy, 29.8% from transportation, 13.6% from agriculture, forestry, and livestock, 7.2% from industrial processes and product use, and 2.5% from waste. This study differs from existing CF calculation studies by focusing on emission distributions from residential stationary energy of each neighborhood. Hence, the priorities of carbon mitigation methods are determined on a neighborhood basis. Among the 18 emission mitigation proposals, better insulation alone will result in 10% energy savings in the existing residential building stock.

Keywords: Urban carbon footprint, Neighborhood greenhouse gas emissions, Stationary energy.

1 Introduction

For decades, the idea of carbon footprint (CF), or the greenhouse gases (GHG) generated during the life cycle of an analyzed system and represented in carbon dioxide equivalents, has been applied to evaluate the potential influence of human activities on global warming [1]. Although carbon dioxide is a natural component of the environment, excessive or extended exposure can have adverse health effects [2]. CF calculations assist in effectively managing greenhouse gas emissions and evaluating mitigation solutions. Using CF analysis, significant emission sources can be identified, and the locations with the most potential for improvement can be selected, resulting in enhanced environmental efficiency and better economic terms for mitigation actions.

The knowledge of a county or city's greenhouse gas (GHG) emissions is useful for sustainable urban planning, particularly for municipalities and law enforcement [3], [4]. Few articles describing valuable fieldwork experiences help the growth of global methodology by shedding light on the laborious effort necessary to calculate a city's CF [5], [6]. In order to limit the extent and consequences of climate change, global carbon emissions must be dramatically decreased. The effort to reduce the carbon footprint of society requires changes in consumption patterns. In this view, cities are a substantial source of greenhouse gas (GHG) emissions [7], [8], [9].

This study aims to construct and present a comprehensive, comparable, and transparent GHG inventory for a county of moderate size. The study is based on GHG calculations in Merzifon for 2021 [10]. To address the aforementioned deficiencies, the data quality is reviewed and Turkey-specific emission factors are constructed. In addition, the emissions inventory is evaluated according to the GPC standard's five primary areas. Furthermore, mitigation measures for GHG emission reduction are offered.

2 Details of Merzifon County

Amasya Province is located in the interior of the Central Black Sea region of Turkey, just south of Samsun, and is surrounded by the provinces of Tokat from the east, Tokat and Yozgat from the south, Çorum from the west, and Samsun from the north (see Fig. 1). According to the most recent data in 2021, Amasya has seven districts, one of which is the central district. It is the largest, with a population of 147,380 people. Merzifon ranks second with 74,727 people. Merzifon is located in the west-center of the provincial borders and is surrounded by Suluova in the east, Amasya and Mecitözü in the south, Gümüşhacıköy in the west, Vezirköprü and Havza in the north (see Fig. 2). Its total surface area is 971 km^2 and it has the third largest surface area after Central district and Taşova.

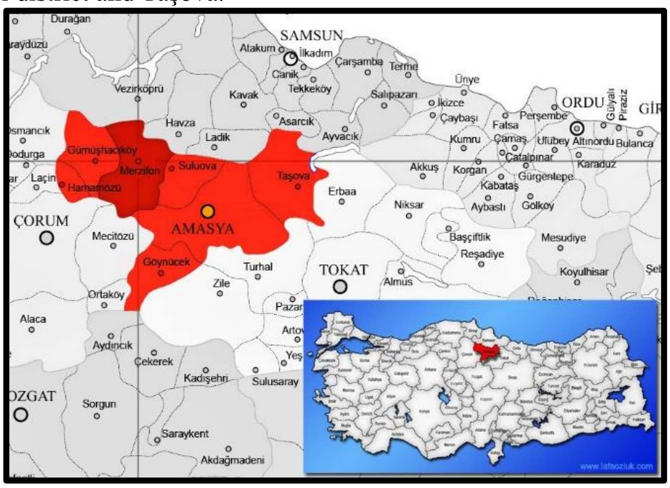

Fig. 1. Strategic Location of Amasya Province and Merzifon District

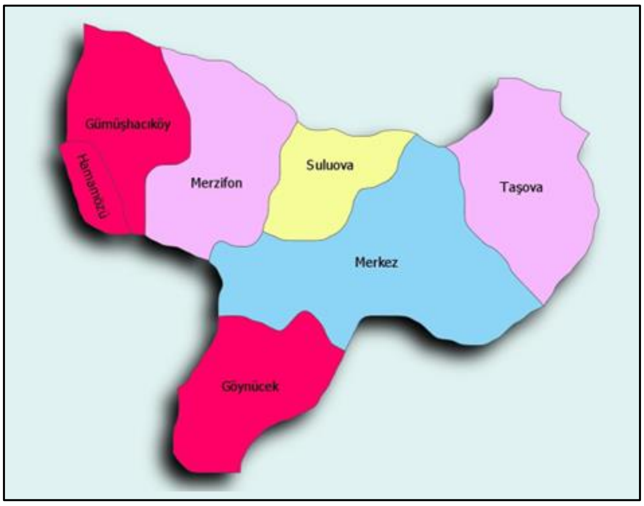

Fig. 2. Districts of Amasya Province

The geographical coordinates of the Merzifon region are 40.873° latitude, 35.463° longitude, and its altitude is 732 m. The north and west of the district are mountainous, and the central and eastern parts are plains. There are the extensions of Taşan Mountain, which reaches 1905 meters in the north, Akdağ in the east, and Çakır Mountain in the south. There is a significant change in altitude in the topography of 3 kilometers in diameter surrounding the Merzifon city center, and the elevation change varies up to 356 meters. In the area with a diameter of 16 km from the city center, the height goes up to 1,456 m. This situation dramatically increases the possibility of benefiting from solar energy and wind.

Merzifon Plain, irrigated by Tersakan Stream, which joins Yeşilırmak near Amasya, is the main agricultural area of the region. In addition, this place is irrigated by the Gümüşsuyu and Solhan Streams, the tributaries of Tersakan Stream.

While cultivated land (65%) and artificial surfaces (29%) are covered throughout the area within 3 kilometers of the Merzifon city center, the share of cultivated land decreases to 52% in the area of 16 kilometers. In comparison, the percentage of the forested area increases to 25%.

Agricultural products have an important place in the economy of the Merzifon district. Wheat, sugar beet, barley, sunflower, lentil, vineyard and garden products, and fruits such as cherries and apples are grown. In addition, the Organized Industrial Zone, which has developed significantly in recent years, has given the city the appearance of an industrial city.

The Province welcomes at least 50,000 tourists annually. Although Merzifon has a significant and old historical heritage dating back more than two thousand years, with its compatriots actively involved with the Turkish Independence War, and well-known local gastronomy, the city receives very few tourists. It is now common belief that any region that wants to become a major player in tourism, such as Merzifon, has to show to the potential visitors that as a tourist destination, they care about the environment, global warming, the history and the archeological treasures and the leaders of the region are modern and open-minded. They are actively involved with sustainability and mitigation of carbon emissions towards a zero-emission goal.

3 GPC Calculation Methodology for Carbon Footprint Emissions

This study was conducted and prepared according to GPC (Global Protocol for Communities GHG Emissions Inventories) jointly developed by the World Resources Institute (WRI); C40 World Cities Initiative and the International Council for Local Environmental Initiatives (ICLEI) for the district of Merzifon.

The methods related to the emission inventory used to date vary greatly, and the inconsistency in the results made the national carbon footprint calculations inextricable by combining the studies conducted on a regional basis. This inconsistency is the main reason why GPC was developed. In particular, this method is formed by about a quarter of the megacities and local governments all over the world. It seems that it will be used until a better one is developed and gains greater acceptance.

The first order of business before starting the inventory studies is to determine the boundary of the inventory study (Inventory Boundary) where the emission inventory will be calculated. The inventory limit can be a county, municipality, province, or region. However, if the waste produced in a local municipality, for example, is stored outside the boundaries of the district, then the waste collection site should also be considered to be within the inventory boundary. The inventory boundary for the Merzifon district is shown in Figure 3.

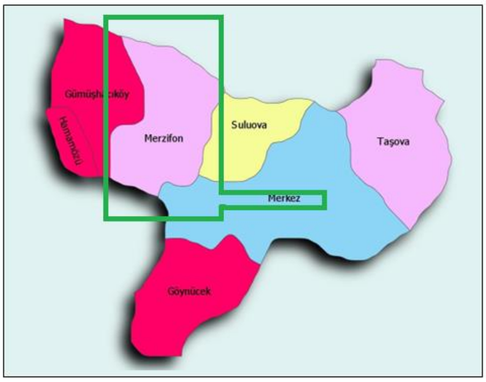

Fig. 3. Carbon Emissions Inventory Boundary for Merzifon District

According to GPC, greenhouse gas emissions are handled on the basis of six main sectors [11]. These six sectors are:

- Stationery energy.
- Transportation.
- Waste.
- Industrial processes and products use.

• Agriculture, forestry, and other land use.
• Emissions outside geographical boundaries from activities of the local area.

In this context, energy inventory studies are classified into three groups in scope. These scopes are given in Table 1.

Table 1. Scope Definitions for a Local Government Area

SCOPE	**Definition**
SCOPE I	GHG emissions within the boundaries of the local government region
SCOPE II	GHG emissions from the consumption of electricity, heat, steam, geothermal energy, cold water, and similar resources located outside the boundaries of the local government and reaching the city with the help of a network.
SCOPE III	GHG emissions from activities within the boundaries of local government but occurring outside the geographical boundaries

The emission sources evaluated in this study prepared according to the GPC method are summarized in Table 2. Table 2 gives the emission sources and coverage areas within the scope of GPC and located in Merzifon. Accordingly, in terms of stationary energy, almost all sub-sectors exist in Merzifon. In transportation, only on-road transportation is taken up in Scope 1. Although generally, air transportation and off-road transportation are handled in separate scopes, they are evaluated together for Merzifon. Generally, air transportation is considered Scope III. Solid waste is collected by the Municipality; then, it is transported to a neighboring district that has solid waste landfills where it is disposed of.

There is an additional deviation from the GPC Protocol. Namely, the project team had to add Scope II for industrial processes and industrial product use sector because there are industrial establishments located in the Merzifon Organize Industrial Zone that uses electrical energy in industrial processes. In addition, because most of the industrial entities shied away from separating the energy used for production from other uses, all fuel and electrical energy consumption had to be included under the stationary energy. It is hoped that the following carbon footprint report will separate all different uses of energy.

Finally, the fuel consumption in tractors used for agriculture is specified in the agriculture, forestry and, land use sector under Scope I.

Table 2. Emission Sources in Merzifon and the Scope Details as Defined by GPC Protocol

Sector	Sub-Sectors	Scope I	Scope II	Scope III
STATIONARY ENERGY	Residential Buildings	✓	✓	✓
	Commercial and Institutional Buildings and Facilities	✓	✓	✓
	Manufacturing Industries and Construction	✓	✓	✓
	Renewable Energy Industry	✓	✓	✓
	Agricultural, Forestry and Fishing activities	✓	✓	✓

TRANSPORTATION	On road transportation	✓	✓	✓
	Air Transportation and Off-Road transportation	✓	✓	✓
WASTE	Solid Waste Disposal	✓		✓
	Wastewater Treatment and Discharge	✓		✓
INDUSTRIAL PROCESSES and INDUSTRIAL PRODUCT USE	Industrial Processes	✓	✓	✓
	Industrial Product Uses	✓	✓	✓
AGRICULTURE, FORESTRY and LAND USE	Emissions from livestock within the district boundaries	✓		
	Land use	✓		
	Emissions from other aggregate resources	✓		

As seen from this table, almost all of the subsectors under the title of stationary energy sources are present in Merzifon District, creating sizeable greenhouse gas emissions with a share of carbon emissions of around 47% for 2021.

Although there is no railway or rail system within the boundaries of the Merzifon district, there is a civil airport that became operational in 2008, and there are aircraft based in Merzifon. Accordingly, road and air transport were taken into consideration within the scope of emissions in transport.

Solid waste within the city limits is collected by the Municipality and sent to the Amasya Solid Waste Disposal Facilities located on the outskirts of Amasya. Solid waste collected from the villages by the Special Provincial Administration is sent to the same facilities in the same way and is recorded under the Merzifon district. There is a comprehensive liquid waste treatment and discharge facility within the borders of the district, and other liquid wastes collected from the villages are sent outside the borders of the district.

In this context, for the composition of the solid waste collected by the municipality and the criteria used in the calculations, the values specified in the IPCC 2006 Guidelines and 2019 Improvement Reports were used. The values that could not be found for any reason were estimated by the project team with the contributions of the relevant municipality department managers. The results are given in Table 3.

Table 3. Composition of Solid Wastes Collected by Municipalities (%) [12]

Region	Western Asia
Country	TÜRKİYE
Food Waste	48.7
Garden and Park Waste	6.8
Paper and Cardboard	8.1
Plastic	5.9
Glass, porcelain, and earthenware	3.4
Other	26.1
Total	100

Greenhouse gas emissions originating from industrial processes and industrial products, on the other hand, include greenhouse gas emissions originating from non-energy uses of fossil fuels as well as those originating from direct energy consumption. As a general principle, greenhouse gas emissions occur as a result of processes that physically or chemically change a material. Among these greenhouse gases, CO_2, CH_4, N_2O, HFC, and PFC are released. If there are production establishments that fit this definition among the industries in Merzifon, emissions from fossil fuel consumptions of these establishments other than stationary energy are evaluated under this heading. Some industrial establishments located in the organized industrial zone (OIB) in Merzifon district comply with this definition, and the emissions of these organizations are evaluated under the title of OIB industry. As to the industrial product use within the district, the most used industrial products are industrial oils, refrigerants, and asphalt. Fossil fuels consumed in processes such as tractors, heating, and irrigation in greenhouses are considered stationary energy consumptions in agriculture, forestry, fisheries, and other land uses. In addition to constant consumption, significant greenhouse gas emissions may occur in these areas. This group includes emissions from land use, from uncontrolled biomass combustion, intestinal emissions from cattle, poultry, and other animals, and from land management.

4 Determination of Emission Factors for Turkey and Merzifon

In order to calculate the carbon footprint of a location, the first step is the calculation of the emission factors that are valid for Turkey for the year in question, 2021. All factors used in GPC calculations, including electricity generation and consumption, are either calculated by the research team in this section or taken from reliable sources. If, for some reason, a valid coefficient cannot be found for Turkey, or a specific emission cannot be calculated from the absence of emission factor/data, then EU values are used; if not, DEFRA (UK) and US values are used, respectively.

Emission factor calculations start with the emission coefficients that emerge during the electricity generation, transmission, and distribution stages on a national basis. Calculation results are given in Table 4.

Table 4. Greenhouse Gas Emissions for Electricity Production and Consumption in 2021

Emission, Electricity Production, and Consumption Parameters	
Production, Transmission, and Distribution Losses 2021	
Total Electricity Production 2021 (MWh)	330,805,853
Transmission and Distribution Losses (%)	15%
Greenhouse Gas Emissions	**kg GHG/kWh**
Total Direct Emissions of CO_2 (kg CO_2/kWh)	0.494
Total Direct Emissions of NO_x (kg NO_x/kWh)	0.000149
Total Equivalent CO_2 Emissions (CO_2 e/kWh)	**0.5340**
Total Direct Emissions of SO_2 (kg SO_2/kWh)	0.0016

Emission coefficients of heating fuels used in other buildings and facilities, especially in residences, can be seen in Table 5. Although emission coefficients do not directly involve and include SO_2 emissions, they are also reported in this study.

Table 5. Emissions from Commonly Used Heating Fuels

FUEL	Quality Description	Lower Calorific Value (Kcal/kg)	Emissions Per Kilogram From Fuels		
			kg CO_2 /kg	kg SO_2 /kg	kg NO_x /kg
Soma A-B	Lignite medium	2692	0.562	0.0035	0.0121
Tunçbilek	Lignite high	3589	0.499	0.0093	0.0190
Imported Coal	High	6273	0.570	0.0014	0.0053
Coal Average	-	4185	0.544	0.005	0.012
Natural Gas	-	8,250 kcal/m^3	1.8671	0	0.0084
Diesel	-	10,200 kcal/kg	2.6142	0.0007	0.0013
Fuel Oil	-	9,860 kcal/kg	2.9676	0.032	0.0015
Wood	Normal	4,000-4,500	1.64	0.000126	0.0063
Stubble*	-	~2,500	1.5	0.00025	0.0035

*Estimated

The emission factors of fuels used in transportation are given in Table 6.

Table 6. Emission Coefficients of Aircraft and Land Vehicles Vehicle Fuels Sold in Merzifon in 2021

Fuel Type	Emission Level	Merzifon Percent of Vehicles (%)	CO_2 eq. Emissions (Kg/l)	
			EU Average	Turkey
Jet Fuel	Low	-	3.1	3.1
Gasoline	Medium	75	2.25	2.35
	High	25	2.31	3.0
	Low	-	2.50	3.5

Diesel	Medium	10	2.681	2.8
	High	25	3.5 – 6.0[1]	3.5 – 6.0
	Low	65	8.0 – 10.0[1]	8.0 – 10
LPG	-	-	2.40	2.5

[1]*https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.html*

There is a significant amount of cattle, sheep, and poultry in the Merzifon district. Greenhouse gas emissions from bowel movements and feces of these animals are given in Table 7.

Table 7. Emission Coefficients from Farm Animals

Farm Animal	CH_4 (including animal feces)	NO_x	CO_2-e
Cattle and Buffalo	100 kg	0.35	2,892.8 kg
Goat-Sheep	6 kg	1.27	504.6 kg
Horse – Donkey – Mule	20 kg	0.30	639.5 kg
Poultry	0.03 kg	0.32	85.6

5 Calculation of Total Greenhouse Gas Emissions in Merzifon

This study calculates energy consumption and related carbon emissions on a neighborhood scale within the city limits. As far as it is known, this is one of the first neighborhood-based calculations available in the literature.

YEDAS is the electricity distribution company, and AKSA is responsible for the natural gas distribution in Merzifon District. It should be noted that natural gas is only available in the city borders and not in the villages. The distribution of electricity subscribers in Merzifon District in 2021 can be seen in Table 8. The minimum, maximum and, average values in the table are basically given on a monthly invoice basis. While making the calculations, mainly average values were used. As can be seen, the total number of electricity subscribers is 39,438.

Table 8. Distribution of Electricity Subscribers in Merzifon District in 2021

SUBSCRIBER GROUPS	MINIMUM	MAXIMUM	AVERAGE
Building Construction	279	324	305
General Lighting	102	116	111
Places of Worship	100	111	105
Communal Building Use	780	978	882
Residences	31,293	32,988	32,345
Commercial, Tourism, and Other Activities Related to Customers	125	586	495
Commerce and Trade Offices	2,701	3,688	2,963
Street Lighting	233	234	234
Government Offices (No production activity)	154	195	178
Agricultural Irrigation + Village Agricultural Irrigation	228	583	459

Martyrs' Families and Veterans	86	90	88
Other	236	317	278
TOTAL	36,317	40,210	38,443

Likewise, the distribution of natural gas subscribers in Merzifon District in 2021 can be seen in Table 9. Accordingly, there are a total of 24,962 natural gas subscribers in Merzifon in 2021.

Table 9. Distribution of Natural Gas Subscribers in Merzifon District in 2021

SUBSCRIBER GROUPS	NUMBER
Residences	23,763
Places of Worship	33
OIB Industrial Companies	80
Martyrs' Families and Veterans	16
Government Offices	60
Public Schools	47
Commercial Companies	874
Others	89
TOTAL	24,962

Merzifon has twenty neighborhoods, some of which date back hundreds of years. These neighborhoods are shown in Table 10. It should be noted that for the number of electricity and natural gas consumers, average figures are taken. As was explained before, the number of users changes throughout the year. According to the table, the population of the neighborhoods combined is 61,371 in 2021.

Table 10. The Data on the Neighborhoods of Merzifon for the Year 2021

Neighborhoods	2021 Neighborhood Population	Number of Residences	Number of Electricity Consumers (Average)	Number of residences heated by Natural Gas
Abidehatun	2,018	1,039	932	634
Bağlarbaşı	2,879	1,454	1,315	928
Bahçelievler	10,663	4,425	4,531	3,728
Buğdaylı	558	249	205	154
Camicedit	1,110	560	509	362
Eski Camii	275	222	194	85
Gazimahbup	1,236	653	653	424
Hacıbalı	2,008	1,209	1,135	583
Hacıhasan	765	580	405	191
Harmanlar	7,063	3,102	3,154	2,457
Hocasüleyman	535	494	320	167
Kümbethatun	278	196	140	54
Mahsen	9,695	4,254	4,309	3,181
Mehmet Akif Ersoy	2,393	1,289	1,083	725
Naccar	236	179	144	84
Nusratiye	1,175	687	573	319
Sofular	6,270	3,606	3,170	2,507

Tavşan	593	391	597	231
Yeni	6,338	2,804	2,569	2,111
Yunus Emre	5,283	2,187	2,404	2,063
TOTAL	61,371	29,580	28,339	20,988

Heating in the Merzifon district is carried out by burning natural gas, coal, wood, and some fuel oil. Table 11 gives the 2021 distribution of heating fuel percentages in all the neighborhoods.

Table 11. 2021 Distribution of Heating Fuel Percentages in Merzifon District Neighborhoods

Neighborhoods	Natural Gas	Wood	Coal	Fuel Oil
Abidehatun	61.00%	9.00%	30.00%	-
Bağlarbaşı	64.00%	8.00%	28.00%	-
Bahçelievler	84.00%	4.00%	12.00%	-
Buğdaylı	62.00%	9.00%	29.00%	-
Camicedit	65.00%	8.00%	27.00%	-
Eski Camii	38.00%	14.00%	48.00%	-
Gazimahbup	65.00%	8.00%	27.00%	-
Hacıbalı	48.00%	12.00%	40.00%	-
Hacıhasan	33.00%	15.00%	52.00%	-
Harmanlar	79.00%	5.00%	16.00%	-
Hocasüleyman	34.00%	15.00%	51.00%	-
Kümbethatun	27.00%	17.00%	56.00%	-
Mahsen	75.00%	6.00%	19.00%	-
Mehmet Akif Ersoy	56.00%	10.00%	34.00%	-
Naccar	47.00%	12.00%	41.00%	-
Nusratiye	47.00%	12.00%	41.00%	-
Sofular	70.00%	4.00%	10.00%	16.0%
Tavşan	59.00%	9.00%	32.00%	-
Yeni	75.00%	6.00%	19.00%	-
Yunus Emre	94.00%	1.00%	5.00%	-
General Average	74%	4%	20%	2%

Although cooling is not generally needed, cooling is available in the hospitality sector, some businesses, and industrial facilities. Especially since there is intense electricity and natural gas consumption in the military facilities, airport, and industrial zone in the district, it is necessary to look at these consumptions in detail.

The main fuels used for heating and transportation purposes in Merzifon in 2021, apart from electricity are;

- Coal
- Wood
- LPG (dwellings, businesses, industry, and transportation)
- Diesel
- Gasoline
- Jet fuel

The distribution of these fuels to consumers in 2021 and the total amounts consumed is discussed in the results and discussion part.

While the solid waste and wastewater produced in the Merzifon district are produced within the city boundaries, the disposal of solid wastes takes place outside the borders of the district, and treatment and the disposal of the wastewater is within the borders of the district. There are no sanitary landfills or operated open landfills (garbage) within the boundaries of Merzifon. However, with the habit of many years, approximately 25% (5,830 tons of garbage) of solid waste collected in villages and neighborhoods goes to wild landfills within the boundaries of the district. In recent years, the decreasing trend in wild storage has become evident. As a matter of fact, for the last six months, no wild landfill operations have been noted. This is also evident from the number of waste trucks operating between AKAB (Amasya Solid Waste Disposal Site) used for solid waste landfills in the Amasya district and the Merzifon district has doubled on a weekly basis. The total amount of medical waste in Merzifon in 2021 is 100 tons. There is a comprehensive sewerage infrastructure and treatment plant in the Merzifon district. As it is known, in a large part of Merzifon, 59,942 people benefit from sewage and treatment water facilities, and the remaining population consists of 13,907 people. In addition, in 2021, it was accepted that there was a certain amount of industrial wastewater, approximately 5-8% in Merzifon as well as domestic wastewater.

In 2021, 83,000 m^2 of hot asphalt and 63,000 m^2 of surface asphalt were used in the Merzifon district, which amounts to approximately 825 tons of asphalt and 10,000 tons of stone chips use. The total quantities of industrial and automotive oils consumed in the entire the Merzifon district, including the industry, the airport, and public offices, are demonstrated in tons in Table 12.

Table 12. Industrial and Automotive Oil Consumption in Merzifon District in 2021

Oil Type	Consumption in Merzifon (tons)
Vehicle Oils	233.1
Industrial Oils	190.7
Marine Oils and Greases	41.0
Kerosene	5.4
Waste oil	18.7

Refrigerant consumption in the Merzifon district is primarily due to public institutions, the airport, refrigerators and air conditioners in residences, and businesses. In addition to this, there is also a sizeable contribution from the industries located in OIB. The list of refrigerants used and released into the environment is given in Table 13.

Table 13. List of Air Conditioning Gases Released to the Environment in Merzifon

User Groups	Refrigerant Type	Quantity (kg)
Public Institutions Group	R410a	20,000
	R134a	15,000
Civil Airport	R22	612
	R407c	22.7
	R410a	22.6

Other Groups	R22	736.24

Information on cattle/sheep and poultry in Merzifon district in 2021 can be seen in Table 14.

Table 14. Number of Farm Animals in Merzifon in 2021

Animal Type	Quantity (2021)
Cattle and Buffalo	20,800
Goat-Sheep	12,502
Horse – Donkey – Mule	252
Poultry	281,863

Considering the total agricultural land, its use in 2021 has been estimated by consulting with the agricultural pesticide and fertilizer companies in Merzifon, together with the information obtained from the Province of Amasya Agriculture Directorate. Herbicides, pesticides, various farm chemicals, antibiotics, and others are grouped as one, under the agro-medicine title, which is presented in Table 15.

Table 15. Total Amount of Fertilizer and Agro-medicine Consumed in Agriculture in Merzifon in 2021

Fertilizer/Agro-medicine	Active Agriculture ($200{,}000 \times 10^3$ m^2)
Fertilizer	15,164 ton
Agro-medicine	145 ton

6 Results and Discussion

Table 16 gives the consumption of fossil fuels in Merzifon District for 2021. Accordingly, the natural gas consumption was in excess of 30 million m^3. Residential buildings have a share of 79% in natural gas consumption, the industry is a distant second with 9.1%, and public buildings are third with 8.8%. In terms of electricity consumption, it is seen that the manufacturing and construction sectors take the first place with 33.1%, housing is in second place with 29.0%, and the group of public and non-governmental buildings completes the first three with 19.2%.

According to the data for 2021, the total electricity consumption in the Merzifon district is 182,503,568 kWh according to the information received from YEDAS, OIB, and the airport, and the actual consumption was found as 183,321,837 kWh as a result of the calculations. The difference is thought to be at the airport. Regarding the fuel consumed in vehicles, diesel is in first place with 331,297 liters. LPG ranks second with 8,458 liters.

Table 16. Fossil Fuel Consumption in Merzifon District

STATIONARY ENERGY							
Sector	Natural Gas (m^3)	Electricity (kWh)	Wood (ton)	Coal (ton)	LPG (ton)	Diesel (ton)	Fuel Oil (ton)
Residential Buildings	23,973,618	53,162,505	9,355	29,912	759	-	444
Public Buildings, including NGOs	2,674,636	35,179,674	-	-	10	246	272
Commercial Buildings	914,569	24,355,550	5,514	3,158	106	-	-
Manufacturing Industries and Construction	2,777,966	60,648,032	-	-	12	-	-
Renewable Energy Industry	-	-	-	-	-	-	-
Agricultural, Forestry, and Fishing activities	-	9,976,076	-	-	-	3,300	-
TOTAL STATIONARY ENERGY	30,340,789	183,321,837	14,869	33,070	887	3,546	716
TRANSPORTATION							
Sector	Gasoline (l)		Diesel (l)		LGP (l)	Jet Fuel (l)	
Total Transportation	2,910		331,297		8,458	3,077	

The distribution of the equivalent CO_2 emissions by sources is given in Table 17 and Figure 4. As can be seen from Table 17, the amount of CO_2-equivalent released to the atmosphere originating from the Merzifon district in 2021 has been calculated as approximately 759,000 tons. Looking at the details of 759,171 tons of emissions, it is seen that the highest emissions come from stationary energy, with 355,787 tons, and from the transportation sector, with 226,381 tons. The emissions from agriculture, forestry, and land use are 102,975 tons, in third place. However, it should be pointed out that 90,767 tons of the total are classified as biogenic carbon emissions.

Table 17. Distribution of the Greenhouse Gases Emissions Among Sectors in Merzifon, 2021

Emission Source	Scope	CO_2-e (Kg)	Percentage Including Biogenic Emissions (%)	Percentage Excluding Biogenic Emissions (%)
STATIONARY ENERGY				
Residential Buildings	I, II	213,755,444	28.6%	32.5%
Residential Buildings	III	3,670,074		
Commercial and Institutional Buildings and Facilities, including NGOs	I, II	68,668,095	9.6%	10.9%
Commercial and	III	4,110,014		

Institutional Buildings and Facilities, including NGOs				
Manufacturing Industries and Construction	I, II	39,574,591	5.8%	6.5%
Manufacturing Industries and Construction	III	4,186,837		
Renewable Energy Industry	I, II	0	0.0%	0.0%
Renewable Energy Industry	III	0		
Agricultural, Forestry, and Fishing activities	I, II	21,133,388	2.9%	3.3%
Agricultural, Forestry, and Fishing activities	III	688,698		
TOTAL		*355,787,142*	*46.9%*	*53.2%*
TRANSPORTATION				
Transportation – On Road	I	216,135,412	28.5%	32.3%
Transportation - Aviation	III	9,359,000	1.2%	1.4%
Transportation – Off Road	I	887,000	0.1%	0.1%
TOTAL		*226,381,412*	*29.8%*	*33.9%*
WASTES				
Solid Waste Disposal	I	4,527,600	2.2%	2.5%
Solid Waste Disposal	III	11,921,500		
Wastewater Treatment and Discharge	I	2,676,040	0.4%	0.4%
TOTAL		*19,125,140*	*2.5%*	*2.9%*
INDUSTRIAL PROCESSES and INDUSTRIAL PRODUCT USE				
Industrial Product Use	I	54,901,200	7.2%	8.2%
TOTAL		*54,901,200*	*7.2%*	*8.2%*
AGRICULTURE, FORESTRY and LAND USE				
Agriculture, Forestry and Land Use - Emissions from other aggregate resources, and land use	I	12,208,278	1.6%	1.8%
Agriculture, Forestry and Land Use - Emissions from livestock	I	90,767,376	12.0%	

TOTAL (Including Biogenic)		*12,208,278*		*1.8%*
TOTAL (Excluding Biogenic)		*102,975,654*	*13.6%*	
GRAND TOTAL				
SCOPE I + II	I + II	725,234,425		
SCOPE III	III	33,936,123		
SCOPE I + II + III	I + II + III	759,170,548		

As shown in Figure 4, 46.9% of total emissions biogenic emissions included are from stationary energy, 29.8% from transportation, 13.6% from agriculture, forestry, and livestock, 7.2% from industrial processes and product use, and 2.5% from waste.

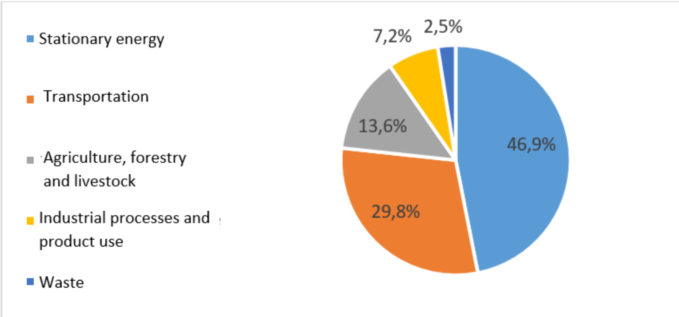

Fig. 4. Distribution of the Greenhouse Gas Emissions Among Sectors in Merzifon, 2021

Although stationary energy consumption takes the first place with 46.9%, it can be seen from Table 17 that the largest share of this sector is in residential buildings, constituting 28.6% of total emissions. Similarly, road transport is the second highest with 28.5%. Farm animals have a separate place in the emission calculations and are considered biogenic carbon emissions. In Merzifon, in 2021, this emission has a share of 12% and has a CO_2e value of 90,767 tons and ranks third.

Considering the savings provided by the energy produced in renewable energy plants in Merzifon, there will be a decrease in total emissions. In this context, when the emission values originating from electricity generation and the losses in the transmission and distribution processes are taken into account, the amount that can be deducted from the total equivalent CO_2 emissions is given by calculating in Table 18.

Table 18. Emission Recovery from Renewable Energy in Merzifon

Scope	CO_2e (ton)	SO_2 (ton)
II	-118,769	- 350.7
III	-17,918	- 53.8

Therefore, 136,687 tons of CO_2e will be reduced from the total emission value. Thus, with the contribution of renewable energy, the total emission value will decrease from 759,171 tons of CO_2e to 622,484 tons of CO_2e. However, since the downgrade process is still not included in the standard, it is given here as information.

In 2021, the population of Merzifon was 77,727. Total greenhouse gas emission per capita is calculated in three different ways and shown in Table 19.

Table 19. Greenhouse Gas Emission per Capita in Merzifon in 2021

Calculation Method	Scope I+II (ton CO_2-e)	Scope III (ton CO_2-e)	Scope I+II per Capita (ton CO_2-e/capita)	Scope I+II+III per Capita (ton CO_2-e/capita)	Scope I+II+III SO_2 Emission (ton SO_2)	Scope I+II+III per Capita (ton SO_2/ capita)
Including Biogenic Emissions	725,234	33,936	9.70	10.15	711.0	0.010
Biogenic Emissions	634,467	33,936	8.48	8.94	711.0	0.010

Considering the total CO_2-e emission value of 759,171 tons of CO_2-e, the per capita greenhouse gas emissions (carbon footprint) will be 9.70 tons/person for Scope I and II and 10.15 tons/person for the total of Scope I, II, and III. These figures are 54% and 61% higher, respectively, than the 6.3 ton/person figure given by TURKSTAT for Turkey in 2020 (Figure 5). However, it should be emphasized that the agricultural forestry, fisheries, and land use values are insufficient for the TURKSTAT figures.

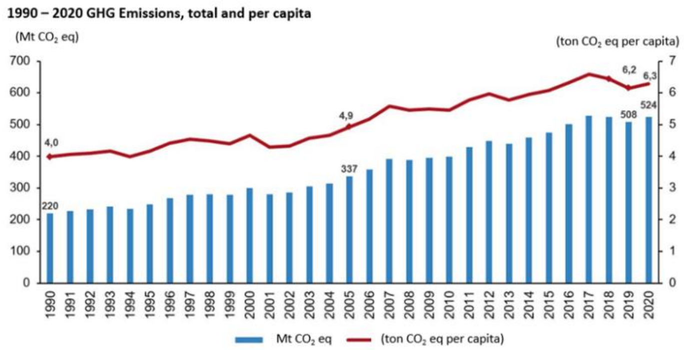

Fig. 5. Greenhouse Gas Emissions per Capita in Turkey, 1990 – 2020 [13]

6.1 Plans for Mitigation of Greenhouse Gas Emissions in the Near Future

When buildings and industrial sectors are examined in the Merzifon district, it is seen that natural gas and electricity are the main energy sources. In addition, coal and wood are also used as fuel sources in some neighborhoods and rural areas with no natural gas and in some businesses. In addition to stationary energy consumption in buildings, there is also intense energy consumption in transportation, agriculture, animal husbandry, and other areas.

Merzifon district, with its structural features, is a district that is a leader in its history and region. The fact that the municipality was established in 1883 is an important proof of this issue. It can be said that it is the leader that directs the Amasya Industry, especially with the OIB and the industrial establishments located within the OIB.

Turkey is a country with a high potential with renewable energy resources. In this context, it can be said that Merzifon district also has an important potential. However, this resource's utilization rate is very low to this date, except for some local applications, especially within the district's boundaries. Within the scope of the project, the evaluation of renewable energy resources in Merzifon district is considered to be quite important.

In Merzifon, renewable energy sources can be considered multidimensional, especially solar and wind. Considering the surrounding agricultural basins, it can be said that the bio-resource also has important potential. However, considering the current technological capabilities, solar and wind are prominent energy sources.

18 measures have been identified by the consulting firm to reduce the carbon footprint with due explanations and completion dates One of the measures taken up here is better insulation of the residential buildings. A detailed survey of the neighborhoods was carried out by the volunteer Municipality workers, and the results are shown in Table 20.

Table 20. Average Number of Floors and Living Areas of the Buildings in the Neighborhoods

Neighborhoods	Average Number of Floors	Average Living Area (m^2)	Establishment of the Neighborhood Building Stock	
			Pre 2008	Post 2008
Abidehatun	2	100	x	
Bağlarbaşı	3	127		x
Bahçelievler	3	142		x
Buğdaylı	2	132	x	
Camicedit	3	119	x	
Eski Camii	2	101	x	
Gazimahbup	3	131	x	
Hacıbalı	3	103		x
Hacıhasan	2	84	x	
Harmanlar	3	108	x	
Hocasüleyman	2	114	x	
Kümbethatun	1	<100	x	
Mahsen	3	108		x
Mehmet Akif Ersoy	2	115	x	
Naccar	2	95	x	
Nusratiye	1	89	x	
Sofular	3	128		x
Tavşan	1	94	x	
Yeni	3	104		x
Yunus Emre	3	106		x

According to this table, some neighborhoods were established pre-2008 and some post-2008. The year 2008 means that a newer version of Building Insulation standards and Guidelines was put into force. Thus, those neighborhoods that are older simply mean they will consume more energy for heating purposes. Requiring better insulation for these buildings alone will save approximately 10 % of energy.

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Significance of the Local Government Contributions on Carbon Footprint Calculations: Merzifon Municipality

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Abstract. In order to implement the Global Protocol for Community-scale Greenhouse Gas Emission Inventories (GPC) guidelines, being the most comprehensive protocol for Carbon footprint (CF) calculations of a county, four stakeholders, government, municipality, energy distribution companies and a competent and independent consultant party with a team of experts on calculating and reporting CF, share the burden. As the main stakeholder, the government has to calculate and publish national carbon coefficients. Subsequently, the government should create local guidelines for carbon emission calculations and require emission reports and related data periodically from municipalities. Data collection and ensuring data quality are significant problems arising in CF calculations' initial phase. The electricity and natural gas companies should provide consumption data for various consumer categories such as residential, commercial, industrial, and NGOs. The municipality, which is at the common point of the stakeholders, has a vital role in collecting the relevant data. Among the tasks that municipalities should carry out, the most important ones are to gather data from energy distributors to keep a record of the sales and consumption of other fuel types, such as coal, wood, fuel oil, and LPG, that are not distributed by the main energy suppliers, to inspect the sales and usage of fertilizers, pesticides, etc. in agriculture, to collect and compile solid and liquid waste compositions. In addition, to calculate and analyze the greenhouse gas emissions effectively, organize the necessary survey studies in cooperation with the consulting party. One of the major difficulties encountered in the CF calculation studies performed with Merzifon Municipality is that there were no declared and reliable national carbon coefficients. Also, it has been known that the government did not enforce such CF calculations for municipalities; hence, the Merzifon Municipality carried out this study voluntarily. Another major problem was the data provided by electricity and natural gas companies was incomplete and chaotic. In the Merzifon carbon footprint calculation case, the competent, trained, and dedicated personnel, aware of the importance of the subject, played an impeccable role in the fast and efficient execution of this project.
Keywords: Urban carbon footprint, Local government, GPC

1 Introduction

The industrial revolution, accompanied by a rapid increase in the production of industrial and commercial goods and consumption of natural resources, has initiated the deterioration of nature through ever-increasing amounts of waste and emissions to the environment. In addition, the ever-rising need for urbanization and modernization, together with the increase in population, has also contributed to this deterioration process. It is evident that urbanization causes a growing number of environmental problems such as traffic, noise, air quality, increase in greenhouse gas emissions, and loss of green areas such as parks within the city limits [1].

Climate change is a critical global issue causing increased awareness of greenhouse gas (GHG) emissions. Environmental awareness was primarily addressed at the climate change framework meetings organized by the United Nations in 1992, and it was widely accepted that emissions should be reduced. The studies by the United Nations, which started with this convention, reached a new stage with the Kyoto Protocol signed by 83 countries in 1997. Although its results are still under discussion, the Protocol came into effect in 2005 and expired in 2012. The date of Turkey's ratification and signing of the Kyoto Protocol is February 2009. This signature is very important symbolically.

The Joint Conference of the Countries, known as the COP (Conference of the Parties), is accepted as the highest decision-making body on the environment and climate change. All member countries are represented at the COP, and the implementation of the decisions taken is discussed at such meetings, and decisions are made on other legal issues.

Perhaps the most important task of COPs is to oversee international communications and evaluate the inventory of greenhouse gas emissions submitted by nations. As a result of this evaluation, the effectiveness of the measures taken in the previous COPs and possible developments are examined, and the results are opened for discussion on whether the main goal can be achieved or not. Among these COP meetings, the most important ones should be considered as COP 3, where the KYOTO Protocol was signed; COP 15, where the Copenhagen Protocol was signed; and COP 21, where the Paris Agreement was signed and adopted with the approval of 195 countries, including Turkey, at the United Nations Convention on Climate Change UNFCCC Conference of Parties in December 2015, is a historical turning point in the global fight against climate change. The agreement is also an important opportunity to leave a world with a more stable, healthier planet, fairer societies, and more vibrant economies, within the framework of the 2030 Sustainable Development Goals (SDGs).

The Paris Agreement draws attention to the fact that greenhouse gas emissions have increased so much that they may be getting out of control and that the climate problem should be resolved in the second half of the century and sets out a global action plan that should be implemented as soon as possible. In principle, the agreement aims to keep global warming well below 2°C compared to the pre-industrial revolution and even aims to limit it to 1.5°C. The Paris Agreement sends a clear message to all stakeholders, investors, businesses, non-governmental organizations, and policymakers that the global transition to clean energy is indispensable.

Paris Agreement, Cities and Local Governments

All cities, large and small, consume 75% of our world's natural resources and 80% of THE global energy supply. As expected, they are responsible for 75% of global carbon emissions. On the other hand, the costs of fossil fuels have been increasing continuously since the 1990s. Naturally, this increase has made it quite difficult for the cities and local governments to meet global targets regarding carbon emissions and whether they can adapt to a plausible carbon economy.

Human settlements, especially cities, dense population, and life and various activities are probably one of the main reasons, perhaps the most important, among the trends and dynamics of global warming and climate change. On the other hand, cities also constitute the groups most adversely affected by air pollution, general pollution, adverse effects of climate change, and heating or cooling processes.

In this context, urban planning, city management and urban transportation require cities to approach climate change problems with a circular economy approach.

The Paris Agreement, COP 21, and its consequences are not the only subsequent treaty initiated by the United Nations on cities, urbanization and local governments. At the same time, the Sustainable Growth Goals (SDG), International Strategy and Disaster Risk Reduction (UNISDR), and HABITAT Programs, which are aimed to be reached by 2030, should also be mentioned. In addition, Resilient Cities, C40 (Mega Cities Community), ICLEI (International Union of Local Authorities), and European Union Mayors Network (Covenant of Mayors) are some of the programs that bring cities together on the axis of the Paris Agreement.

The Paris Agreement is a set of decisions that concern not only 190+ heads of state but also thousands of mayors. While the statesmen state that climate change poses a great threat to humanity and natural life on behalf of their own countries, the same thought should be shared by the mayors of that country as well. As a matter of fact, a record number of (400+) mayors attended COP 21 held in Paris. These mayors all agreed that the Paris Agreement should be implemented starting with local governments. Thus innovative solutions will increase and come faster with the participation of municipalities. In particular, the fact that more than 5 billion people will live in cities by 2050 clearly indicates that cities and local governments must deal directly with both climate change and global warming. Local governments are responsible for the initiation and management of waste and treatment processes, and as such, the complete resolution of the impacts of climate change remains uncertain, with potential future challenges yet to be determined.

The roles of cities and local governments in the Paris Agreement are not very clear and explanatory. The fact that local governments, administrations, non-governmental organizations, and intermediary institutions and organizations are mentioned only three times (Introduction, Decisions 7.2 and 7.5) in the entire treaty clearly reveals the deficiency and ambiguity in this issue. We think that the role and responsibilities of local governments will increase, especially after the realistic determination of the actual national greenhouse gas emissions and global greenhouse gas emissions, which will be given by all countries that have ratified the Paris Agreement in 2023 and will be subject to scientific control. Although they are rarely involved, the Treaty requires cities and local governments to reduce greenhouse gas emissions and adapt to new conditions.

It is particularly recommended that the successful practices achieved in combating this climate change, which is a common problem of humanity, be shared with other countries and cities on common scientific and application platforms. In addition, systemic approaches, best practices, and the urgent development of new standards by intermediary and international organizations are required.

As expected, stationary energy and transportation constitute the two main sectors in cities and local governments of developed and developing countries. Instead of making direct changes in these two sectors, it would be better to prefer the urban planning approach. The second most important issue for local governments and cities is land use and possible changes in use.

These changes may cause an irreversible increase in greenhouse gas emissions under some conditions. In this context, it will be necessary to green the cities and prevent the spread of cities to green areas and rural areas, or at least after making serious plans and calculations of possible greenhouse gas emissions.

The main adaptation issues that cities and local governments will face may be extreme meteorological events and long-lasting conditions. The main ones are local floods that can lead to human deaths, drought near cities and rural areas, and more severe extreme events that will strain the urban infrastructure. Here, too, the solution for mayors may be the acquisition and sharing of information on best practices and consultancy services, careful implementation of lessons learned from similar previous incidents, and advanced warning systems.

Climate change will have significant impacts on human life and nature. According to the IPCC [2], the Mediterranean region, including Turkey, is expected to be affected by climate change in the ocean, coastal and offshore areas, water, agriculture, food production, human health, and cultural heritage. Some studies predict that Turkey will experience effects such as drought, famine, forest fires, temperature increase, increased insect populations, sudden floods, heavy rainfall, lightning strikes, rising sea levels, erosion, and salinization of water resources [3], [4].

Most of these effects are also observed in Merzifon. Climate-related risks such as disruptions in precipitation regimes, sudden floods, increased drought periods, decreased water resources, and changes in seasonal patterns are being addressed. In 2020, the Merzifon Rainwater Collection Project was completed in partnership with Ilbank Inc. to take measures against flash floods. The fact that 95% of the city's drinking water is obtained from wells and the flow rate in these wells decreases every year has also brought up the need for measures related to drinking water. In this context, a financing of €15,000,000 was allocated to Merzifon Municipality for the renewal of Merzifon's drinking water pipelines and tanks within the framework of the Sustainable Cities Project-2 Additional Financing, which was financed by the World Bank and allocated by Ilbank Inc. The project, whose preparation stages are ongoing, is expected to begin construction in 2024.

The city is preparing itself infrastructure-wise to combat climate-related risks, but it also aims to reduce its emissions and take measures accordingly as a social responsibility by acknowledging the harm it causes to the environment. Therefore, the "Carbon Footprint Project," which appeared in the 2019 local elections manifesto of the Merzifon Mayor, aimed to calculate the city's carbon emissions. This goal was achieved with the calculations completed in 2022, and the next target has been set to prepare a sustainability report in 2023 [5].

2 Carbon Footprint Studies for Local Governments

There are several studies in the literature addressing carbon footprint calculation methodologies. The study providing a literature review of methods for measuring carbon footprint at the local level identified several carbon footprint calculation methods, including the territorial and consumption-based approaches. The study found that different methods can produce significantly different results, highlighting the importance of selecting an appropriate method for the specific context. The authors suggest that local governments should use a hybrid approach that considers both the territorial and consumption-based approaches to accurately measure their carbon footprint [6].

This study estimates the carbon footprint of Austrian municipalities by considering local emissions, imports, and supply chain impacts. The authors used a hybrid life cycle assessment method to estimate the carbon emissions from various sources such as energy use, transportation, and waste management. The study found that the transportation sector was the largest contributor to carbon emissions, followed by energy use and waste management. There are several studies done for local governments in various countries, including China [7], Chile [8], and Australia [9]. Chinese study finds that urbanization has led to a significant increase in carbon emissions and energy consumption in Ningbo, China. The Chilean study found that the transportation sector was the largest contributor to carbon emissions, followed by energy use and waste management. On the other hand, Australian research finds energy use is the highest contributor.

Overall, these studies suggest that carbon footprint studies for local governments are crucial in identifying the sources of carbon emissions and developing effective policies and programs to reduce carbon emissions. These studies highlight the importance of carbon footprint studies for local governments and provide insights into the main sources of carbon emissions in local governments. They also suggest that local governments should prioritize investments in sustainable transportation and renewable energy to reduce their carbon footprint.

GHG calculations, primarily based on GPC standards and the IPCC inventory method, include four major steps as shown in Figure 1. The first step in GHG calculation, according to GPC, is to establish the boundary of the community. This includes determining the community's geographic area, identifying the sectors that contribute to GHG emissions within the boundary, and determining the base year against which to compare future emissions. The next step is to identify the sources of GHG emissions within the boundary. This includes direct emissions from stationary and mobile sources and indirect emissions from purchased electricity, heating, and cooling. Once the emissions sources have been identified, the next step is calculating the inventory.

This involves collecting data on the activity levels of each emissions source, such as the amount of fuel consumed or the number of kilometers driven, and applying emissions factors to calculate the amount of GHG emissions associated with each activity.

All factors used for GPC calculations are either recalculated or taken from reliable domestic sources. Where reliable or acceptable emission factors needed for any greenhouse gas calculation can't be obtained for Turkey, then EU emission factors, if also unavailable, in the order of sequence, DEFRA, United Kingdom, or USA factors can be employed. The next step is to report the GHG emissions inventory. This involves summarizing the emissions data into a comprehensive report that includes the community's emissions profile, emissions trends over time, and potential reduction strategies. In addition, it involves reviewing the inventory to ensure its accuracy, completeness, and compliance with the GPC protocol. In summary, the GPC provides a clear and consistent framework for calculating GHG emissions at the community scale. Following the GPC protocol, communities can accurately measure and report their emissions, track their progress toward reducing emissions, and identify potential reduction strategies.

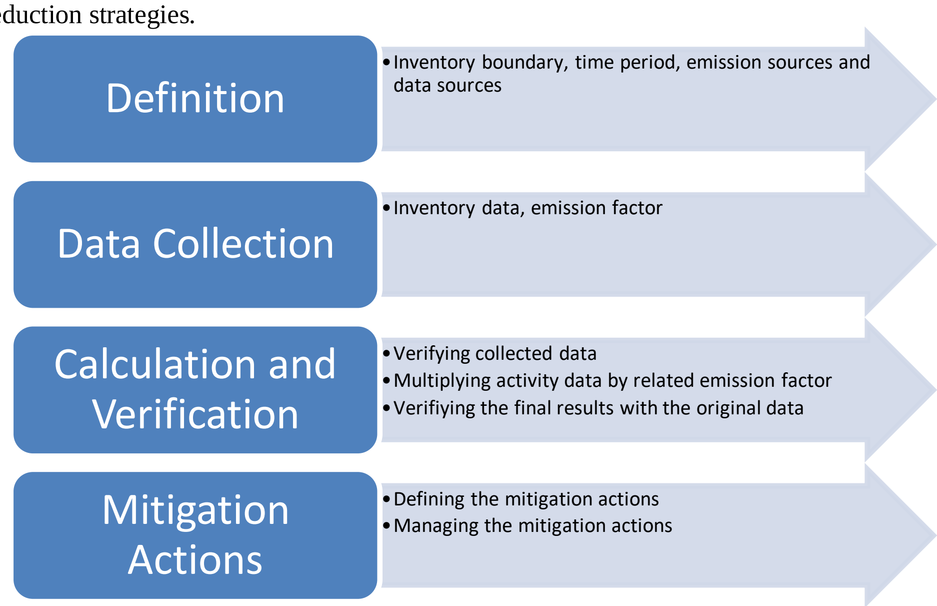

Fig. 1. Major Steps of CF Calculation Methodology

Collecting greenhouse gas (GHG) inventory data for a county can be a complex and time-consuming process, requiring collaboration and coordination among various stakeholders. Figure 2 demonstrates the data collection process for calculating the CF of a county according to GPC.

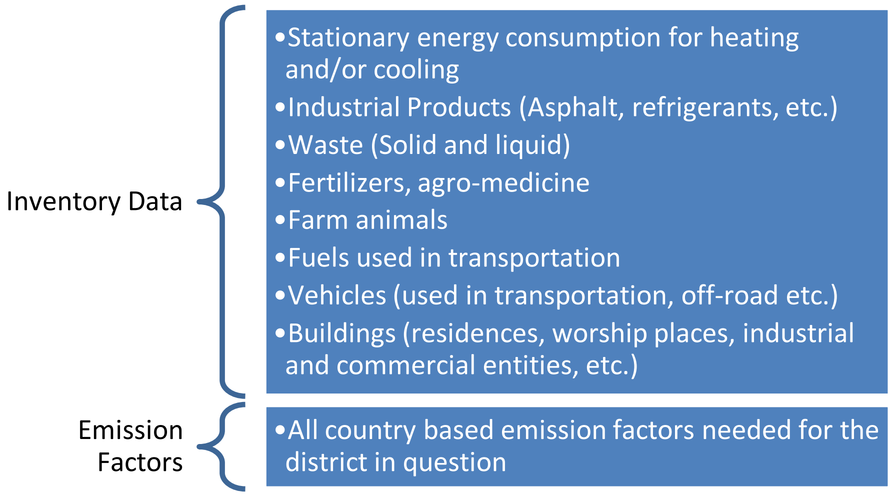

Fig. 2. Data Collection

The first step is to establish the boundary and scope of the inventory, which includes defining the geographic area of the county and identifying the sectors that contribute to GHG emissions. The sectors typically include energy use in buildings, transportation, waste management, industrial processes, and agriculture. Once the boundary and scope have been established, data collection can begin. The process involves identifying and collecting data on all sources of emissions, including direct and indirect emissions. Direct emissions result from the on-site combustion of fuels, while indirect emissions are associated with the consumption of purchased electricity, heating, and cooling. Data collection can be done through a variety of methods, including surveys, energy bills, and monitoring equipment. In order to ensure the quality and accuracy of the data collected, it is essential to establish quality control measures. This includes cross-checking data with utility bills or other records, ensuring consistency in units of measurement, and verifying the accuracy of assumptions and emissions factors used in the calculations. Technology can also play a role in GHG inventory data collection for counties. Automated monitoring systems and data management software can help to streamline the process and reduce errors, while remote sensing and satellite imagery can be used to estimate emissions from land use changes and forestry. Finally, third-party verification can provide independent assurance of the data's accuracy and completeness, increasing the inventory's credibility. This involves an independent inventory review to ensure its accuracy, completeness, and compliance with established protocols and standards. GHG inventory data collection for a county requires careful planning, stakeholder engagement, quality control measures, technology, and third-party verification. By following these steps, counties can accurately measure and report their emissions, track their progress toward reducing emissions, and identify potential reduction strategies.

Greenhouse gas (GHG) emission factors are used to calculate emissions from various sources, including energy use, transportation, and industrial processes. Emission factors represent the amount of GHG emissions that result from a specific activity or unit of energy consumption. For example, an emission factor for electricity might represent the amount of GHG emissions associated with the production of one kilowatt-hour (kWh) of electricity. Emission factors are developed through scientific research and data analysis. They can vary depending on a range of factors, such as the type of fuel used, the efficiency of the technology used to produce energy, and the geographic location of the emissions source. Using standardized emission factors is important to ensure consistency and comparability of GHG inventories across different organizations and regions. Standardized emission factors are developed by international organizations, such as the Intergovernmental Panel on Climate Change (IPCC), and national governments. However, it is important to note that emission factors are not perfect and can have limitations. For example, they may not accurately reflect the emissions associated with specific activities or technologies. In these cases, site-specific data collection and calculations may be necessary to ensure accurate emissions reporting. In addition, emission factors can change over time as technologies and practices evolve, and new data becomes available. Therefore, it is vital to keep emission factors up to date and to use the most recent and accurate information available. In conclusion, GHG emission factors are a critical component in calculating emissions from various sources. They are used to ensure consistency and comparability of GHG inventories across different organizations and regions. However, the use of emission factors has limitations, and site-specific data collection and calculations may be necessary to ensure accurate emissions reporting.

3 Carbon Footprint Studies for Merzifon County

The province of Amasya, located in central-north of Turkey, has seven districts (counties). Merzifon is one of the oldest districts. With its airport, the ever-growing organized industrial site housing several industries leading in foreign exports in the sectors they are active, high-yielding agricultural land and a population of over 74,000, the Mayor and the top management of the Municipality have the goal of becoming one of the leaders of Municipalities combatting with the climate change in Turkey. The Mayor and his team plan to enact several projects in order to achieve this ambitious goal in a relatively short period.

A complete carbon footprint study involves at least five major stakeholders, namely, the central government, the Municipality, energy distribution companies, the Municipality, the consulting company, and the people of Merzifon. There are also minor stakeholders involved at several stages of the study. Major Stakeholders are shown in Table 1. The table also includes the steps of a successful carbon footprint study.

Table 1. Major Stakeholders and the Steps of Merzifon Carbon Footprint Study

Carbon Footprint Study Steps	Central Government and The Local Offices of the Various Ministries	Merzifon Municipality	Energy Distribution Companies	Consultıng Company	People of Merzifon
Introduction To CF Studies				x	
Training Of Municipality Personnel Who Will Contribute To Data Collection				x	
Data Collection for the year in question	x	x	x		x
Data Verification		x		x	
Data Processing				x	
CF Calculations according to GPC				x	
Report Writıng				x	
Identification of Appropriate Training Topics for the Municipality Personnel				x	
Actual Training of Municipality Personnel				x	
Training Of Interest Groups of Merzifon		x		x	
Training Of Merzifon People with special emphasis on the students		x			
Related Carbon Mitigation Investments		x			x
Support and Household Applications					x

As seen from this table, the major data providers are the Central Government and the local offices of various ministries, energy distribution companies, and the Merzifon Municipality. The Consultant Company is also a data provider. since the Company calculates all the national emission factors with high precision. The Merzifon Municipality and the Consultant Company make data collection and verification.

For the completion of the carbon footprint study according to the GPC method, the data needed for Merzifon is shown in Table 2. This table also indicates the major and minor stakeholders that provide the data.

Table 2. Type of Data Needed and The Stakeholders That Provide the Data

The Data Groups	**Data**	**Major Stakeholders**	**Minor Stakeholders**
Stationary Energy	Subscriber Based Monthly electricity consumption	Electric Distribution Company	Merzifon citizens via questionnaire

	Subscriber Based Monthly natural gas consumption	Natural Gas Distribution Company	Merzifon citizens via questionnaire
	Annual fuel oil consumption	Municipality	Commercial companies, Merzifon citizens
	Annual wood consumption	Municipality	Commercial companies, Merzifon citizens
	Annual coal consumption	Municipality	Commercial companies, Merzifon citizens
	Annual LPG consumption	Municipality	Commercial companies, Merzifon citizens
Transportation	The volume of gasoline sold	Government	Gas stations questionnaire
	The volume of diesel sold	Government	Gas stations questionnaire
	The volume of LPG sold	Government	Gas stations questionnaire
	Jet fuel	Government	Airport management
	Off-road diesel consumption in airport	Government	Airport management, some government institutions
Waste	Solid waste types	Government	-
	Quantity of solid wastes	Municipality and government	-
	Quantity of methane production and combustion at solid waste disposal site	Municipality	-
	Quantity of wild landfill	Municipality and government	-
	Quantity of liquid wastes	Municipality and government	-
	Wastewater treatment plant information	Municipality	-
Industrial Processes	Subscriber Based Monthly electricity consumption	Electric Distribution Company	Organized industrial zone management, industrial companies
	Subscriber Based Monthly natural gas consumption	Natural Gas Distribution Company	Organized industrial zone management, industrial companies
	Annual wood consumption	Municipality	Organized industrial zone management, industrial companies
	Annual coal consumption	Municipality	Organized industrial zone management, industrial companies
	Annual LPG consumption	Municipality	Organized industrial zone management, industrial companies
Industrial Products Use	Refrigerants Consumption	Municipality	Public institutions, airport management, industrial companies
	Vehicle Oils	Municipality	Commercial companies
	Industrial Oils	Municipality	Organized industrial zone management, industrial companies
	Marine Oils and Greases	Municipality	Organized industrial zone management, public institutions, industrial companies
	Kerosene	Municipality	Commercial companies
	Waste Oil	Municipality	Commercial companies
	Asphalt Use	Municipality	

Agriculture Forestry and Land Use	Cattle, Sheep, Poultry and other animals	Municipality	Neighborhood and village headman,
	Fertilizers	Municipality	Commercial companies, local ministerial offices
	Agro-medicine	Municipality	Commercial companies
	Tractors	Municipality	Neighborhood and village headman, related NGOs

4 The Role of Merzifon Municipality in the Study

After the 2019 elections, the Mayor started exchanging ideas with Zeta Information Technologies to calculate the city's carbon footprint and take measures for the future of the city. Merzifon Municipality Strategy Development Department (SDD) led this process on behalf of the municipality. At the end of the process, a carbon footprint calculation was made for 2021.

Both sides agreed that the report would be based on the GPC method. SDD was responsible for collecting the necessary data for the calculations, providing this data to the consulting firm, and working as a team with the consultants throughout the process to ensure that all the calculations were verified.

Initially, the consulting firm organized several informative meetings with the Municipality personnel, industrialists, organized industrial zone group, central government employees residing in Merzifon, village and neighborhood headmen, and other stakeholders. The objective was to acquaint them with global warming and carbon footprint concept. These meetings were followed by informal and formal training sessions for the municipality personnel to collect and verify data.

The second stage required obtaining the necessary consumption data from the YEDAŞ Electricity and AKSA Natural Gas Distribution Companies responsible for electricity and natural gas distribution in Merzifon for 2021. One issue that complicated matters was that the data was incomplete and chaotic. This was not only specific to this project but also a problem for every business sector due to the lack of data integrity and the absence of a common and standard format. It is challenging to develop a format that can satisfy everyone's needs. However, if the country is to prepare for a zero-carbon future, the government must establish a standard data format for electricity and natural gas companies. The consultant firm carefully reviewed and verified the complex electricity and natural gas data obtained by SDD and used in the calculations.

The third stage involved obtaining data from public institutions and organizations, companies in the industrial zone, commercial establishments, and the public. Formal correspondence was conducted, visits were made, and surveys were prepared to verify the data provided by the electricity and natural gas companies and to obtain other data to be included in the carbon footprint calculations.

One of the most important aspects of the project was introducing it to and gaining acceptance from the city's residents. A field team of 40 people was organized under the supervision of SDD. Surveys were conducted in 348 households and 153 commercial establishments in 20 neighborhoods in the city center and 75 households in 5 villages selected based on their geographic location and population density, as well as with a total of 90 neighborhood and village headmen. The surveys generally included the following questions:

- For district households: Information about their residence, size of the family, if it is an apartment building, information about the building, information about the household, and information about the energy sources used.
- For businesses: Information about the building in which the business is located, information about the energy sources used, information about employees, and information about vehicle use if applicable.
- For village households: Information about their residence, information about the household, size of the family, information about the energy sources used, and information about agriculture and animal husbandry.
- For village headmen: Geographical and demographic data about the village, information about commercial enterprises, information about public institutions in the village, information about agriculture and animal husbandry, and questions about how village land is used, number of tractors, and other agricultural machinery. The information obtained was passed to the consultant.

5 Conclusion

Climate change is one of the most significant environmental issues that the world is facing today. The increasing carbon footprint is one of the primary drivers of climate change, which is predominantly caused by human activities. The concept of carbon footprint, which refers to the total amount of greenhouse gases (GHGs) emitted to the atmosphere due to human activities, has become a significant concern for local governments worldwide. Local governments play a crucial role in mitigating the impacts of climate change by reducing carbon emissions within their jurisdictions.

Local governments play a vital role in carbon footprint calculations by developing and implementing policies and programs that reduce GHG emissions within their jurisdictions. They are responsible for managing energy consumption, waste management, and transportation systems, the primary sources of city GHG emissions. Local governments can influence and regulate these sectors through zoning, building codes, and other policies to reduce carbon emissions. For instance, local governments can incentivize the use of public transport, walking, and cycling by providing infrastructure and implementing policies that promote these modes of transportation. Local governments can also reduce carbon emissions by promoting energy efficiency in buildings. Buildings are responsible for a significant proportion of GHG emissions globally, and local governments can influence energy use in buildings through building codes, zoning, and other policies. Local governments can encourage using renewable energy sources such as solar, wind, and geothermal energy to reduce carbon emissions. They can also regulate emissions from industries within their jurisdictions through permitting and regulation.

Local government contributions to carbon footprint calculations are significant because they can substantially impact GHG emissions within their jurisdictions. Local governments can influence and regulate sectors that contribute significantly to carbon emissions, such as energy, transportation, and waste management. By developing and implementing policies and programs that promote energy efficiency, the use of renewable energy, and low-carbon transportation modes, local governments can significantly reduce GHG emissions within their jurisdictions.

Local government actions can also contribute to reducing GHG emissions globally. For instance, cities and regions that are early adopters of low-carbon technologies and practices can serve as models for other regions and cities to follow. They can also influence national and international policies by demonstrating the feasibility and benefits of low-carbon technologies and practices.

Surveys and fieldwork is the most effective way of collecting data for local governments. This allows the Municipality and the Consultant to directly obtain all the required information from the relevant parties. Similarly, data can be collected effectively from all companies trading in fuel and energy types not handled by distribution companies, fertilizer, agricultural pesticides, and firewood in the district.

Merzifon is an important city in terms of industry. The organized industrial zone is constantly growing and becoming quite popular in the region. As of 2023, the zone hosts around 80 companies and 8,000 employees. Another important issue for Merzifon is the presence of a military base and a civilian airport in the district. The data relating to these institutions was also obtained through mutual cooperation.

In terms of carbon footprint calculations, obtaining the desired data is a challenging task. There are some shortcomings in recording, organizing, and classifying the data. Factors such as the incomplete and chaotic data of electricity and natural gas distribution companies, official and private institutions not wanting to share data or being hesitant to share it, and the lack of data-related efforts from the tradespeople make these calculations difficult. Especially regarding the lack of data from tradespeople, municipalities can develop a sample format to ensure the recording of data related to commercial activities.

In conclusion, local government contributions to carbon footprint calculations are significant because they play a vital role in reducing GHG emissions within their jurisdictions. Local governments can influence and regulate sectors that contribute significantly to carbon emissions, such as energy, transportation, and waste management. By developing and implementing policies and programs that promote energy efficiency, the use of renewable energy, and low-carbon transportation modes, local governments can significantly reduce GHG emissions within their jurisdictions. Local government actions can also contribute to reducing GHG emissions globally by serving as models for other regions and cities to follow and influencing national and international policies. It is, therefore, essential for local governments to continue to develop and implement policies and programs that promote low-carbon technologies and practices to mitigate the impacts of climate change.

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