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I. Introduction

Task 7.3 "Methodologies to support the implementation of national adaptation plans" of **WP3** "Impact and Policies Department" aims to support coordination, monitoring and updating of national action plans in compliance with EU directives and international protocols, and further extend them to other countries in the EMME through the Professorship Programme. Research activities conducted under this task have provided robust scientific options to support public organizations with recommendations, guidelines and measurable outputs towards effective design and efficient implementation of the national action plans on climate change and air pollution.

EMME-CARE extended the scope of Task 7.3 to both national adaptation and mitigation plans in order to better comply with

- EU directives (EU Climate Law),
- International protocols (Paris Agreement),
- Optimally align with the EC Green Deal Objectives (on reduction of emissions), and
- Better support, monitor and update national action plans implemented under the relevant departments of the Cyprus Government.

Several nationally and internationally funded projects have been aligned with the EMME-CARE project to provide robust and in-depth scientific knowledge in support of the objectives of these methodologies.

II. National Action Plan on Air pollution

Air quality is, and will likely continue to be, an important issue over the Eastern Mediterranean and the Middle East (EMME) region. Air pollution influences the quality of life, the number of premature deaths, and the frequency and severity of various cardiopulmonary diseases. Cyprus is a receptor of pollution from multiple sources of anthropogenic and natural origin. The island of Cyprus, located centrally in the EMME region, is ideally located to assess current regulations and evaluate observational and model-oriented benchmarking methodologies and thus provide insights on the applicability and effectiveness of action plans that aim to reduce air pollution levels, for the country itself and the wider region.

II.1. National and Regional air quality legislation in Cyprus

In order to improve air quality and reduce health impacts, countries provide and adopt integrated legislative approaches. Air quality legislative instruments are structured into different levels ranging from European Union directives to national legislation, and governmental implementation mechanisms. The Directive 2008/50/EC of the European Parliament and of the Council of 21/05/2008, on **ambient air quality and cleaner air in Europe**, brings three of the four previous directives and Decision 97/101/EC in a single directive, introducing new elements, such as the regulation of the $PM_{2.5}$ quality targets and the importance of contrasting pollutant emissions at source. In case of exceedances, the Directive obliges Member States to draw up Air Quality Plans (AQP), in order to bring the pollutants within the target limits. The AQP is a strategic planning instrument introduced by Directive 2008/50/EC.

The monitoring and management of Air Quality in Cyprus is based on the provisions of the Atmospheric Air Quality Laws of 2010 to 2020 and a series of Regulations that define atmospheric air quality limits for specific pollutants. The competent authority for the implementation of the above legislation is the Ministry of Labour and Social Insurance, through the Department of Labour Inspection (DLI) and in particular the Air Quality and Strategic Planning Section, which maintains the necessary infrastructure, and has the necessary know-how, experience and equipment for the implementation of the above legislation. The legislative framework governing air quality issues in Cyprus is fully harmonized with the relevant European legislation and concerns the following legislation:

- The Atmospheric Air Quality Laws of 2010 to 2020 (Law 77(I)/2010, Law 3(I)/2017 and Law 20(I)/2020), which harmonize Cypriot legislation with the provisions of European Directives 2008/50/EC on ambient air quality and cleaner air for Europe and Directive (EU) 2015/1480 amending certain annexes of Directives 2004/107/EC and 2008/50/EC, which lay down rules on reference methods, data validation and location of sampling points for air quality assessment.
- The Atmospheric Air Quality (Arsenic, Cadmium, Mercury, Nickel and Polycyclic Aromatic Hydrocarbons in the Atmospheric Air) Regulations of 2007 and 2017 (R.A.A. 111/2007 and R.A.A. 38/2017), which harmonize Cypriot legislation with the provisions of the European Directive 2004/107/EC regarding these species
- The Atmospheric Air Quality (Limit values of Sulfur Dioxide, Nitrogen Dioxide, Particles, Lead, Carbon Monoxide, Benzene and Ozone in the Atmospheric Air) Regulations of 2010 and 2017 (R.A.A. 327/2010 and R.A.A. 37/2017), which harmonize Cypriot legislation with the provisions of the European Directive 2008/50/EC.

The purpose of the legislation is to:

- identify and determine the objectives for the quality of atmospheric air in the Republic, in order to avoid, prevent or reduce the harmful effects on human health and the environment as a whole,
- assess air quality based on methods and criteria commonly accepted in the European Union and other transnational and regional organizations, in which the Republic participates
- Collect information on ambient air quality in order to facilitate the fight against air pollution and nuisances as well as the monitoring of long-term trends and improvements resulting from national and Community measures,
- ensure that this air quality information is made available to the public,
- maintain the quality of the ambient air, where it is good and improve it in other cases, and
- promote greater cooperation between Member States in terms of reducing air pollution.

Air pollution concentrations in Cyprus should obey limit and target values posed by the European Union regulations that address the following pollutants:

- Nitrogen oxides (NOx), i.e. nitrogen monoxide (NO) and nitrogen dioxide (NO_2)
- Sulfur dioxide (SO_2)
- Ozone (O_3)
- Carbon monoxide (CO)
- Particulate Matter (PM_{10}, $PM_{2.5}$)
- Benzene (C_6H_6)
- Carbon monoxide (CO)
- Heavy metals and more specifically: Lead (Pb), Arsenic (As), Cadmium (Cd) and Nickel (Ni)
- Polycyclic Aromatic Hydrocarbons (PAHs)

The Air Quality Monitoring Network in Cyprus was established in 2006 with the aim to protect and inform the public regarding the air quality in Cyprus and currently includes nine (9) stations. These monitoring stations have the ability to perform measurements of different pollutants, such as nitrogen oxides (NO, NO_2, NOx), ozone (O_3), sulphur dioxide (SO_2), carbon monoxide (CO), Particulate Matter (PM2.5, PM10) and benzene (C_6H_6). Furthermore, several meteorological parameters are being monitored, such as: wind direction (W/D), wind speed (W/S), ambient temperature (T), relative humidity (R/H), barometric pressure (B/P) and solar radiation (S/R), by using automatic instruments for continuous measurements.

II.2. Current situation of air quality

The monitoring and investigation of the air quality situation in Cyprus falls under the governmental authority of Department of Labour Inspection. Annual technical reports regarding air quality are being publicly available through the website https://www.airquality.dli.mlsi.gov.cy/reports with material from own analysis and research collaborations and relevant scientific publications. Under the framework of EMME-CARE, aligned with the objectives of several projects (LIFE-SIRIUS, ACCEPT, AQ-SERVE, META-Sat, etc), the air pollution general characteristics over Cyprus have been captured:

Concentrations of most pollutants and the heavy metals are below the corresponding limit values set by the Cyprus and are in accord with European Legislation. <u>Exceptions exists for ozone (O_3) and Particulate Matter with aerodynamic diameter less than 10μm (PM10), where exceedances of the corresponding limits are observed</u>. In case of ozone, the relevant exceedances are mostly due to the climatic conditions in Cyprus such as high ambient temperatures and high solar radiation, which contribute to the production of O_3 as well as the transboundary pollution with the transportation of O_3 and its precursors from the East Mediterranean and other upwind countries.

Exceedances of limit values are also observed in the case of PM10, which are due to <u>both anthropogenic and natural sources</u>. Anthropogenic sources are emissions from vehicles, central heating and various industrial sources. Natural sources are airborne dust from the arid and partially arid areas (deserts) of North Africa and the Middle East, resuspension of dust from roads, agricultural areas and uncovered areas of cities during periods of drought, as well as sea salt. Due to the Mediterranean dry climate in Cyprus, the resuspension of the soil may also play an important role in the emissions of PM. From analysis of the emission inventory, it was found that the main emission sources of PM in Cyprus are road transport, power plants, dry cleaning installations, the central heating of houses and the uncontrolled diffuse emission sources as well as waste burning, the mines and quarries and the unpaved roads.

<u>The annual average values of PM10 in all towns are higher than the annual limit value</u>. However, during the last three years, there was a small reduction in the mean PM_{10} concentration. Also, the number of daily exceedances exceeds the maximum allowed number of exceedances of 35 per year. It is noted that, after the subtraction of the exceedances due to natural sources (sea salt, dust from deserts), <u>the final number of exceedances is below the 35 per year allowed</u>.

In the *Cyprus Initial National Air Pollution Control Programme (DLI, 2019)*, the identification of the different PM10 emission sources was studied for the application of mitigation strategies for the aforementioned emissions. The characterization of PM and the contribution of the main PM sources in different points in Cyprus were investigated. The dust emitted from the roads showed a high contribution in the measured PM10 concentration in the Nicosia Traffic Station (NICTRA) with about 24%. The highest contribution from road dust was found in NICTRA station during winter and spring, while a comparatively lower contribution was found during summer. The burning of fossil fuels was found to contribute about 11% of the PM_{10} concentration in NICTRA station. The weekly variation of the air pollutants shows that their concentrations in the atmosphere were decreasing in Nicosia by about 20%, especially on Sundays. The largest reductions were observed in city centres and the smallest reduction in Agia Marina Xyliatou regional Background station. In addition, the daily variation of pollutants' concentration in urban areas showed two peaks during the morning and the night related to the emissions from traffic during the high traffic hours and domestic heating activities.

In the framework of EMME-CARE a new study was performed to better assess the temporal variability of air pollution in Cyprus, using the longest available dataset, to our knowledge, of gaseous trace pollutants and one of the longest for EMME, covering a span of 17 years (2003–2019). Additionally, to tackle the spatial variability of pollution, in this work, data from different environments covering curb monitoring sites operating at the largest cities of the island, along with residential, industrial, background and free-troposphere monitoring stations were utilized in the analysis. Results from this research have been published in Vrekousis et al., (2022). The main outcomes include the following:

- Comparing background median values of main primary pollutants to the pollution footprint of residential and industrial areas, indicates that local pollution in Cyprus is not negligible for NOx, CO and SO_2.
- Relatively low O_3 median mixing ratios are recorded in the cities, whereas at the background and free troposphere stations, the respective value is twice as high. Notably, high O_3 values are found in the whole EMME region controlled by synoptic meteorology, enhanced insolation and the proximity of precursor species' emissions
- For all pollutants, except O_3, there is a decreasing trend over all eight stations included in the study. In contrast, at four out of the eight monitoring stations, a statistically significant increase in O_3 levels is found. Further analysis of O_3:NOy ratio revealed that these regions lie in the VOC-limited regime where a decrease in NOx amounts due to mitigation strategies can lead
- to an increase in O_3.
- Focusing on O_3, in the majority of the sites, the highest values are found in summer, and the lowest in winter, mostly due to a) its enhanced photochemical production during high insolation and b) the transport of air massed advected from long distances.
- The speciation and quantification of the contribution of local traffic, urban-background and regional components of pollution in Nicosia and Larnaca cities suggest that, on average, for both cities, 99 % of NO emanates from traffic and urban background sources. The same is true for 92 % of the NOz. On the other hand, almost 40 % of SO2 and 34 % of CO originate from regionally transported sources. Interestingly, 29 % of O3 seems to be depleted in cities, with the rest being transported and/or formed regionally.
- Most significantly, the background and the free-troposphere stations can be characterized as NOx-limited while the urban centers, residential sites and industrial sites are VOC-limited, meaning that a reducing only NOx would not lead to reduction of O3 levels. This is extremely vital when planning pollution control strategies that target O3 reduction. In that case, control actions targeting simultaneously NOx and VOC reductions are needed.
- Moreover, satellite data of tropospheric NO2 vertical columns revealed the strong signal of all major emissions hotspots over Cyprus, including cities and powerplants. However, it was found that the observed NO2 pollution from power plants is not proportional to their operating capacity pointing to less efficient pollution control strategies for the two powerplants (PP4 and PP5) found in the north of the island.
- Clustering analysis was used to quantify the intensity of each hotspot plume and, subsequently, its contribution to the sum of NO_2 pollution sources over Cyprus. The results revealed that all major cities and powerplants combined contribute overall only around 10 % to the tropospheric NO_2 columnar amounts in Cyprus. The rest emanates from other local sources, and from the regional NO_2 levels confined from the neighbouring countries Egypt, Israel, Lebanon and Turkey, as seen from the NO_2 distribution over the East Mediterranean region.

In another study, performed for the EMME-CARE project, near-real-time chemical composition of submicron aerosols (PM1) and source apportionment of carbonaceous aerosols was performed for the first time in Nicosia (Christodoulou et al., 2023). Despite the fact that no clear PM1 pollution episodes of several consecutive days could be observed over Nicosia, very intense peaks (above 40 µg m^{-3}) were recorded systematically every evening during the cold period. The main components of these peaks were identified as carbonaceous aerosols (BC and OA) and were mostly attributed to local emissions from heating with only little contribution from local meteorology. Source apportionment of BC performed for both cold and warm seasons solidified the conclusions reached through the OA source apportionment, with almost half of fossil fuel BC (BCff) being of regional origin with the Middle East playing an important role. This result was quite unexpected given that local traffic emissions have been so far considered the dominant contributor to BCff in urban background environments. These conclusions have numerous implications related to PM regulation and the efficiency of local abatement strategies (in particular regarding traffic emissions), health (combustion aerosols being considered as particularly adverse for human health with higher oxidative potential than other species, rendering them extremely toxic), and climate (major influence of light absorbing aerosols from Middle East fossil fuel emissions).

These updated results provided by recent research from EMME-CARE studies contain vital information on the implementation peculiarities of the national action plan on air quality in Cyprus and provide robust scientific material for its current and future updates.

II.3. Methodologies for effective implementation of action plans

To address the problem of exceedances, but also to improve air quality with regard to other pollutants, a National Action Plan for the Improvement of Air Quality is prepared by the responsible national agency (Department of Labour Inspection), the final version of which was approved by the Council of Ministers in 2008 and submitted to the European Commission. The progress in the implementation of the Action Plan is monitored by the DLI as the competent Authority, through the Technical Committee defined in Article 2 of the Laws on Atmospheric Air Quality from 2010 to 2020 and in which representatives of five other co-competent Ministries participate (Ministry of Interior, Ministry of Transport, Communications and Works, Ministry of Energy, Trade and Industry, Ministry of Agriculture, Rural Development and Environment and Ministry of Health), representatives of the Cyprus Scientific and Technical Chamber and the Cyprus Federation of Environmental Organizations. In October 2022, the National Action Plan has been revised (NAP, 2022).

To reduce the effects of air pollution, especially in cities where the majority of the European population lives, it is important to define effective planning strategies to improve air quality. To this end, Member States must design and implement air quality plans that include emission reduction measures in accordance with Framework Directive 96/62/EC on the assessment and management of ambient air quality. Air pollution reduction measures are categorized as "Technical Measures" and "Non-Technical Measures" and are used and evaluated with the aim of quantifying the effectiveness of air pollution reduction and their implementation costs. Technical Measures are applied to reduce emissions before the emission of gaseous pollutants enter into the atmosphere. Non-Technical Measures reduce human factors and are related to changes in human behaviour (environmental education and information, car sharing) or technologies, which, by reducing energy demand, reduce fuel consumption (use of high-efficiency boilers).

It has been highlighted in the last version of the national action plans, that cost-benefit analysis of the proposed measures should constitute a significant part of the decision-making process. Thus, further to the estimate of emission reduction levels, the health financial benefit (premature mortality cost of statistical life, years of life lost, years of life with disease) should be taken into account versus the actual cost of the implementation of the measure and decide the priority of application.

Designing and implementing an air quality plan to improve air quality in polluted areas where air quality limits are exceeded means:

1. characterizing emission sources
2. estimating the contribution of these sources to atmospheric concentration levels
3. determining these sources in priority order of their treatment.

To identify emission sources and estimate their contribution to air pollutant concentrations, source analysis techniques are applied, in which atmospheric concentrations at receivers must be known from measurements and/or using models. The application of these techniques allows an understanding of the maximum possible improvement in air quality that can be achieved by reducing emissions from these sources due to the implementation of emission reduction policies to protect human health and the environment. Study of the identification of sources of PM_{10} with chemical analyses is a continuous procedure, to determine the percentage of natural sources contribution so that realistic measures can be applied for the reduction of anthropogenic sources.

In addition, the assessment of the impact of emission reduction scenarios on air quality is mainly based on the combination of measurements from air quality monitoring networks and results from models. The models are used as tools to support the decision process of air quality measures and management. The models can help by calculating concentrations of air pollutants in areas not covered by monitoring stations and can estimate the impact on air quality in emission scenarios. The inventory of atmospheric emissions should be as detailed and specific as possible, with the aim of better characterizing the reference situation.

II.4. Applications of methodologies in support of national action plan (Cyprus)

The CARE-C "Emission Team" (Impact & Policy Department) has been established in 2020 with the objective to provide technical support to the Cypriot authorities responsible for the emission reporting of Air Pollutants (AP) (Department of Labour Inspection, DLI) and Greenhouse Gases (GHG) (Department of Environment, DoE).

The 2020 submission is the first submission for which our emission team at **CARE-C/IPD** has worked for the preparation of the emissions and the reporting. Activity data are collected from the different responsible bodies such as the Statistical Service, Department of Environment, Department of Labour Inspection, etc, in order to calculate with a top-down approach the GHG and air pollutants emissions for Cyprus, using the methodologies and emission factors described in the IPCC 2006 Guidelines. The emissions have been calculated for the years 1990-2018 and corrections have been applied after the "TERT" and "ERT" recommendations during the review process. The sectors taken into consideration for the reporting of emissions include energy, agriculture, industrial processes, waste and LULUCF. The emission reporting process deals with annually updated total emission fluxes per sector.

The **preparation of the annual national inventories of greenhouse gas emissions** is done by **CARE-C/IPD** in accordance with the provisions of:

- the United Nations Framework Convention on Climate Change (UNFCCC)

- the Paris Agreement
- the guidelines of the Intergovernmental Panel on Climate Change (IPCC) for the preparation of the 2006 greenhouse gas emissions inventories and the corrections released since then
- the Regulation EU 2018/1999 of the European Parliament and of the Council on the Governance of the Energy Union and Climate Action

Similarly, the **preparation of annual greenhouse gas emissions projections** is done by **CARE-C/IPD** in accordance with the provisions of the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement and the Regulation EU 2018/1999 of the European Parliament and of the Council on the Governance of the Energy Union and Climate Action has been performed.

The estimation of energy demand/production forecasts based on the three scenarios (without measures, with existing measures and with additional measures) and estimation of emissions up to the year 2050 is provided in a "biennial report" and "National Communication 8" to the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC), a dedicated report in accordance with the provisions of the Governance Regulation to the European Commission (covers the years up to 2050), and a report on revised policies and measures and greenhouse gas emission projections for the revision of the National Energy and Climate Plan (**Figure 1**).

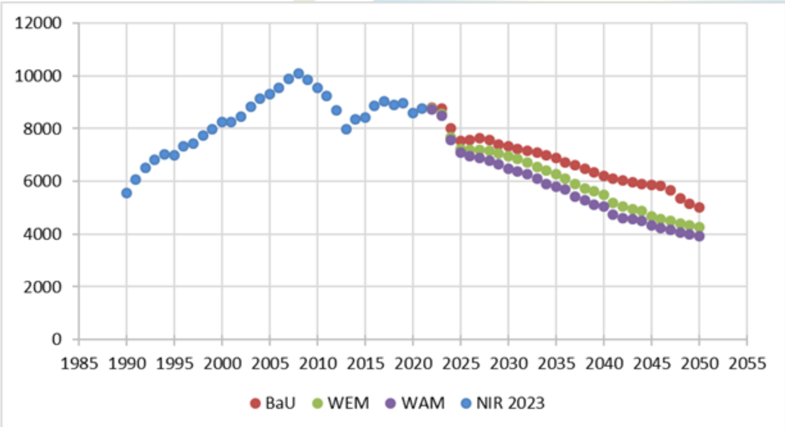


Figure 1. Mid-century BaU, WEM and WAM Projections of total national GHG emissions (excluding LULUCF)

Towards the achievement of the objectives of the above-mentioned methodologies, it is of paramount importance to establish emission analysis systems that focus on the attribution and spatialization of emission fluxes per sector.

In the framework of Task 7.3, a detailed training was performed on the TREFIC software developed by ARIA Technologies (**EMME-CARE Boost Project#1**) to enhance the quality of existing and future spatial emission inventories of Cyprus. The TREFIC software estimates emissions from road transport, a main key category for Cyprus, within GIS software, and is based on the COPERT 5 model, being consistent with the methodology currently in use in the non-spatial inventories. Activity data have been collected from the different responsible bodies such as the Statistical Service, in order to calculate with a top-down approach the GHG emissions for Cyprus, using the methodologies and emission factors described in the IPCC 2006 Guidelines for 2020 (previous calculations done for 1990-2018). The sectors taken into consideration for the reporting of emissions are Energy, Agriculture, IPPU, Waste, and LULUCF. The data have been used for the submission under Art. 7 of Regulation (EU) No 525/2013 of the European Parliament and of the Council of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at the national and Union level relevant to climate change and repealing Decision No 280/2004/EC.

In detail, CARE-C scientists developed in-house capacity on inventory development systems utilizing ground-based and satellite data. The CARE-C team identified and processed national data from the Department of Labour Inspection (Air Quality Group) on large point sources in the island. The information includes the thermodynamics parameters (height, diameter, speed, temperature) for certain sources. EPRTR LPS database was used for Cyprus to demonstrate how to process emission data for dispersion modelling. Information on the capacity of power plants in the northern part of Cyprus was scarce.

CARE-C prepared the Activity report from the Department of Labour Inspection which provides annual emissions for different (sub)sectors for the preparation of the gridded inventory for area sources, for the identification of different sources of GIS data (CyI DB, CLC, National GIS providers, GE…) to be used for spatial distribution of emissions.

Training sessions were conducted on the TREFIC software allowing computation of emissions from the road traffic sector by providing information on vehicle fleet and the traffic flow on the road network (**Figure 2**). Data related to fleet and fuel use were collected on fleet composition with different macro-categories (PC, HDV, LDV, 2W) divided into sub-categories (fuel types, euro standards and size distribution), fuel consumption expressed as total fuel consumption for road transport, mean mileage by vehicle category, and monthly fuel sales.

Information related to traffic counting on the Cyprus road network was not available, and thus a statistical approach was used to estimate road traffic emissions with the "AriaCity Everywhere (ACE)" tool. Different methodologies for preparing the road traffic emission inventory for Cyprus were discussed during the project. For the reason of consistency with the other sectors, the final emission file for road traffic is based on the total emissions reported by the Dept. of Labour Inspection for road traffic. Spatial disaggregation was thereafter made with the output (fuel consumption) from the "Aria City Everywhere" calculation which included open data on traffic flow and moreover the traffic counting available from the "Open Transport Map" project (best available data). The northern part of the island includes areas, which, though part of the EU, are not under the control of the Republic of Cyprus. Since formal statistics for this part of the country are not available, the emission team used available tools to improve the information of pollution sources. The road links in the northern part of Cyprus were included in the calculations (OSM data), and the emissions in the northern part were estimated by comparing fuel consumption in the northern and the southern part of Cyprus resulting from the ACE calculation.

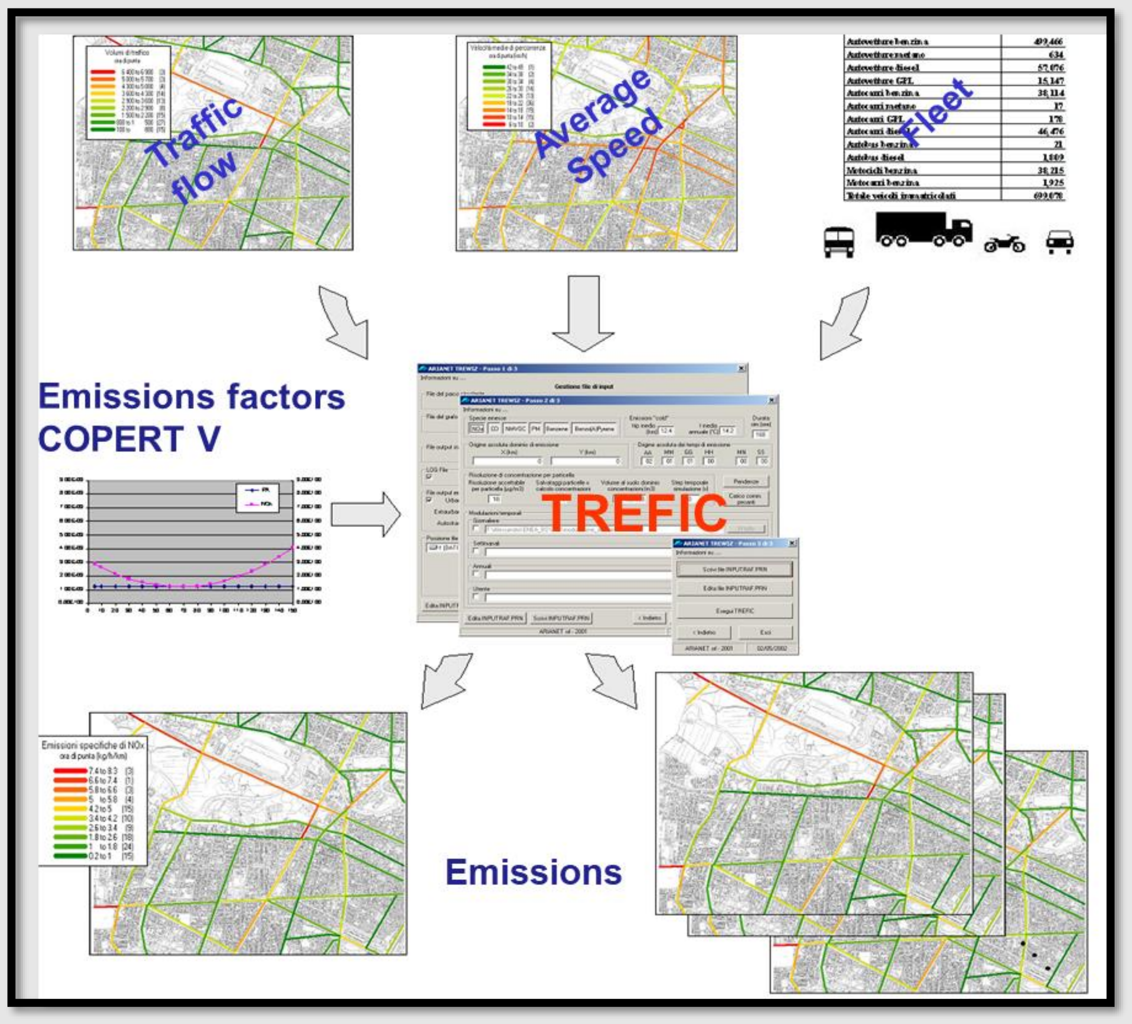


Figure 2. TREFIC schematic description of processes and data acquiring steps

II.5. Applications of methodologies in support of national action plan (Lebanon)

CARE-C scientists established a partnership with Lebanon that led to an important joint publication, titled "*Updated national emission inventory and comparison with the Emissions Database for Global Atmospheric Research (EDGAR): Case of Lebanon*" published in Environmental Science and Pollution Research (IF 2020-2021 4.223). In this collaboration a new inventory of air pollutants over the country has been compared against existing inventories and discrepancies have been investigated (Shami et al., 2022).

Comparable to Cyprus, Lebanon, a small country located on the Eastern coast of the Mediterranean Sea, is considered a hotspot in the Mediterranean basin and Middle East region in terms of air pollution. Air quality in this country is addressed by CARE-C as a benchmark for similar studies throughout the region. Lebanon suffers from many air pollution-related problems such as an unsustainable road transport sector, unmaintained power plants, and an unregulated private diesel generator sector. Therefore, there is a crucial need to conduct accurate air quality modelling studies over the country, based on a refined emission inventory, to be able to study scenarios and to come up with effective policies to mitigate air pollution impacts. However, the development of a national emission inventory is difficult work to complete since the necessary data such as activity profiles, energy consumption, and fleet characteristics are not always available, even more challenging in a data-scarce environment such as Lebanon.

A complete national emission inventory was first developed for Lebanon for the base year of 2010 by Waked et al. (2012). Later on, a collaboration between the American University of Beirut (AUB) and the Ministry of Environment (MoE) estimated emissions trends for the two key sources of air pollution in Lebanon, diesel generators and light-duty vehicles (Baayoun et al. 2019). In the current EMME-CARE collaboration (Shami et al., 2022), a national emission inventory for Lebanon for the base year of 2010 was developed, comprising a combination and refinement of the previous work. Discrepancies between the newly developed inventory and EDGAR based on total emissions were compared, contrasted and discussed. Using the year 2010 enabled us to uniquely and innovatively identify discrepancies and for the first time estimate the uncertainties systematically for all pollutants.

This new study was further motivated by the outcomes of Salameh et al. (2016) that there is strong evidence that global inventories (including EDGAR) underestimate the emissions by up to a factor of 10 for the transportation sector in Lebanon, and an assessment of anthropogenic emission inventories was deemed necessary as these emissions could be much higher than expected at least from the road transport sector, with implications for many countries in the EMME region. For the first time, this work with the contribution of CARE-C scientists accounted for the emissions of heavy-duty vehicles separately leading to a significant revision of previous values in this sector. Also, this study improved markedly upon the previous work by the American University of Beirut (Baayoun et al. 2019) and the Ministry of Environment of Lebanon. Prescribed best practices following EEA standards and recommendations and current state-of-the-art methodology were applied.

Through the comparison of the newly updated inventory with EDGAR emission totals for the year 2010 for all sectors and species, and previous estimates it was found that there were several differences emerging (**Figure 3**). The emissions reported in this paper supersede previously published estimates (Waked et al. (2012) by including emissions for key sources of air pollution in Lebanon that were previously unaccounted for: diesel generators (a major source of energy production and pollution), air and ship transport, and residential space heating and cooking. A large difference in the estimated emissions is also found for the industry sector. This work also improved on previous assumptions (both in Waked et al. 2010 and in EDGAR) and used a more detailed analysis of activity data. Major efforts were placed in treating and refining the data, hence revealing how differently that contributed to major discrepancies in the final results of the inventories.

Figure 3. Comparison of main pollutant emission fluxes over Lebanon per sector (left) and totals (right) with already existing emission inventories

II.6. Applications of methodologies in support of national action plan (EMME)

Egypt: Technical Training has been provided to the National Research Centre of Egypt (2021) to provide holistic training starting from aerosol sampling techniques, to chemical speciation training using the newly acquired analytical instrumentation funded by the World Bank, to data exploitation using receptor and inverse modelling. The goal is to identify sources of pollution in Cairo and actively reduce their levels as part of their national (Egypt) Action Plan.

CARE-C researchers also provided training and knowledge transfer to El Hoda, representing the Egyptian Environmental Affairs Agency. Under the Pollution Management and Environmental Health Program ("PMEH"), established by the World Bank in 2015 to actively drive the "Pollution management and environmental health" business theme, WBG ensures strong collaboration between implementing and supporting countries in making important progress to solve above-addressed issues. One of the 7 pilot cities supported by the PMEH program is the Greater Cairo Area (GCA). The aim was to establish a systematic and consistent approach to develop full-scale Air Quality Management Plans that identify cost-effective abatement options based on solid data and analytical underpinnings.

U.A.E: A tangible example of stakeholder support is the Transport of Hydrocarbons and Ozone Formation downwind of the Arabian Gulf (THOFA) campaign that concluded recently (3-24 of June 2023). The campaign aimed to provide the Environment Agency Abu Dhabi with valuable information regarding the ozone pollution loading transported in the country as result of chemical reactions upwind. A significant challenge to the air quality in the EMME region is the high levels of tropospheric ozone, which in the UAE the 8-hour mean frequently exceeds 120 ppb (the limit according to the Directive 2008/50/EC is circa 60 ppb) during summer, a powerful greenhouse gas with detrimental effects on human health and the environment. As we uncover the dynamics of tropospheric ozone formation and its ties with the regional precursor sources in this vastly understudied region, policy-makers will be able to construct more effective measures to control and regulate emissions, thereby mitigating ozone-related concerns.

II.7. Applications of methodologies to improve GHG emission monitoring (Cyprus)

A methodology was also established to define an inventory for CO_2 and CH_4 emissions in Cyprus, at a high spatial and temporal resolution to be able to support the Department of Environment DoE) in meeting its targets related to GHG emission monitoring, reporting and validation reporting obligations (**Figure 4**). Cyprus is a party to the UN Framework Convention on Climate Change (UNFCCC), which was agreed upon in 1992 and entered into force in 1994, and the Kyoto Protocol to that Convention, which was agreed upon in 1997 and took effect in 2005. To achieve this goal, the general approach followed was to utilize the Cyprus National Greenhouse Gas Inventory (NIR, **table 1** for CO_2 and **table 2** for CH_4) that presents the CO_2 and CH_4 emissions for each sector, for the year 2019, in gigagram (Gg) and consider the sectors responsible for the main part of the CO_2 and CH_4.

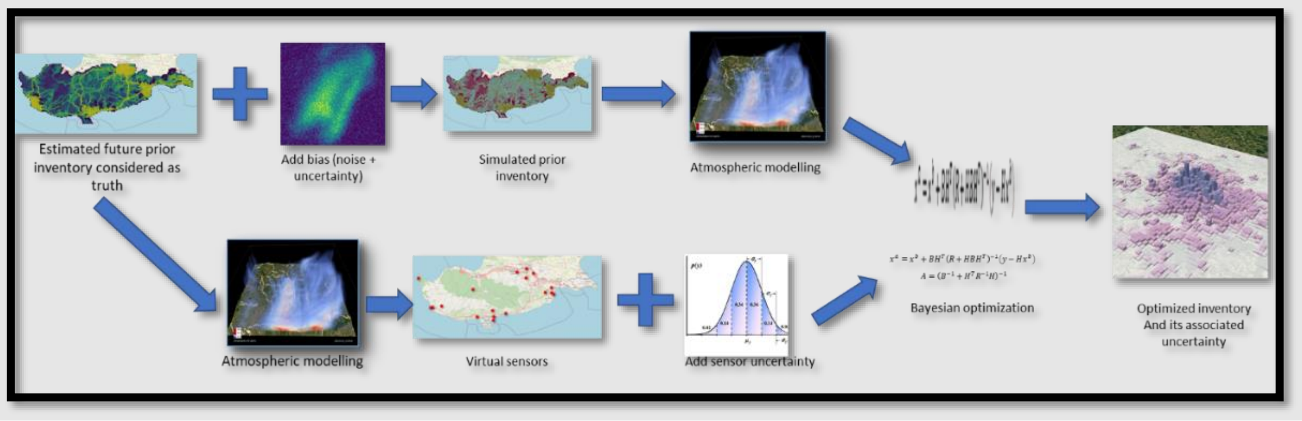


Figure 4. Methodology to produce a high spatial and temporal resolution GHG national emission inventory for Cyprus

The calculations have been performed for the energy, industry, waste, agriculture, residential and road transport sectors based on national statistical data and regional/global databases (**Figure 5 and 6**).

Table 1: CO_2 emissions for year 2019 in Cyprus and share of each sector

Sector	CO_2 emissions considered (Gg)	CO_2 share in Cyprus emissions	Cumulated CO_2 share in Cyprus emissions
Fuel consumption for energy industries	*3342**	*45.5*%*	*45.5%*
Fuel consumption for road transport	2121.3	28.9%	*74.4%*
Industrial processes from cement industry	789.2	10.8%	*85.2%*
Fuel consumption for cement industry	414.2	5.6%	*90.8%*
Fuel consumption for commercial and institutional	330.5	4.5%	*95.3%*
Fuel consumption for other manufacturing industry and construction	145.3	2.0%	*97.3%*
Fuel consumption for residential	116.4	1.6%	*98.9%*
Fuel consumption for agriculture	83.1	1.1%	*100.0%**
Industrial processes from other mineral industries	25.2	0.3%	*100.4%**
Industrial processes from other industries	3.6	0.0%	*100.4%**

Table 2: CH_4 emissions for year 2019 in Cyprus and share of each sector

Sector	CH_4 emissions considered (Gg)	CH_4 share in Cyprus emissions	Cumulated CH_4 share in Cyprus emissions
Unmanaged waste disposals	16.13	45.3%	45.3%
Enteric fermentation	10.83	30.4%	75.8%
Managed waste disposals	3.83	10.8%	86.5%
Manure management	1.97	5.5%	92.1%
Waste water treatment	1.82	5.1%	97.2%
Biological treatment for solid waste	0.24	0.7%	97.9%
Fuel consumption for commercial and institutional	0.24	0.7%	98.5%
Fuel consumption for road transport	0.14	0.4%	98.9%
Fuel consumption for energy industries	*0.13**	*0.4%**	*99.3%*
Fuel consumption for residential	0.08	0.2%	*99.5%*
Fuel consumption for cement industry	0.07	0.2%	*99.7%*
Fuel consumption for agriculture	0.06	0.2%	*99.9%*
Fuel consumption for other manufacturing industry and construction	0.02	0.1%	*99.9%*

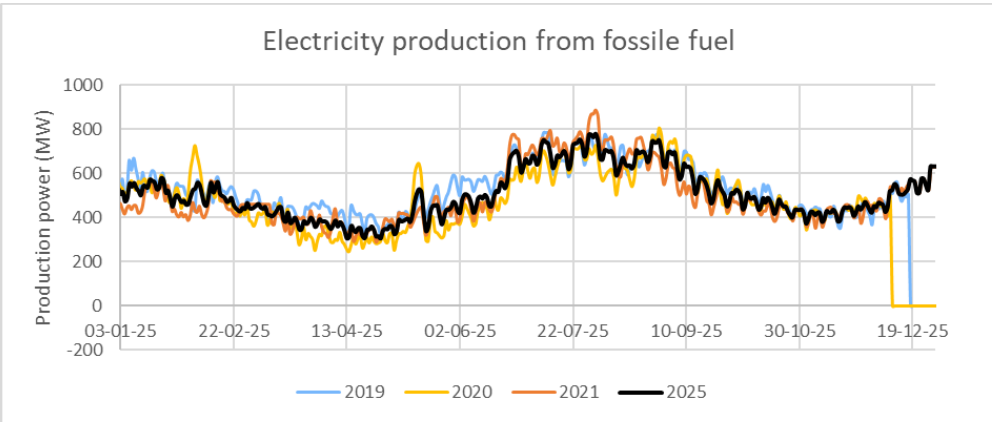
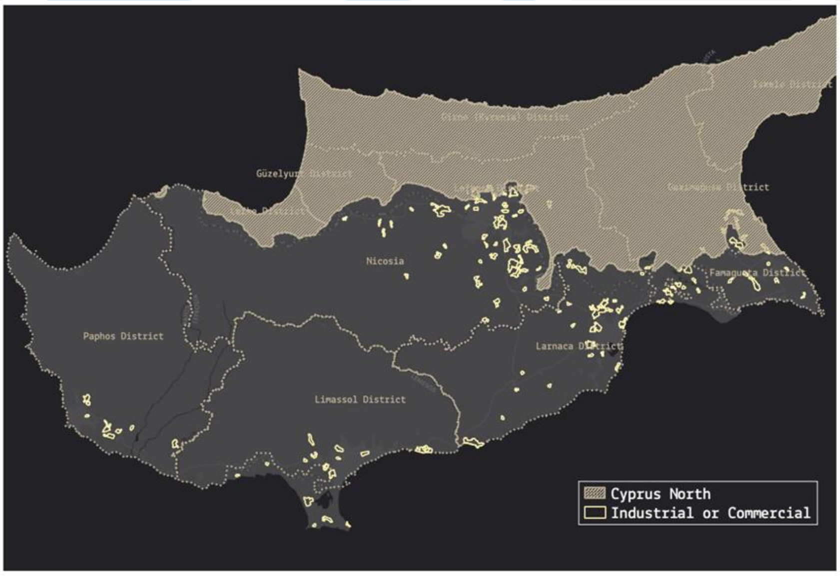


Figure 5. Location of the three main power plants in Cyprus and island wide electricity production for 2019, 2020 and 2021 (projection for 2025 in black line)



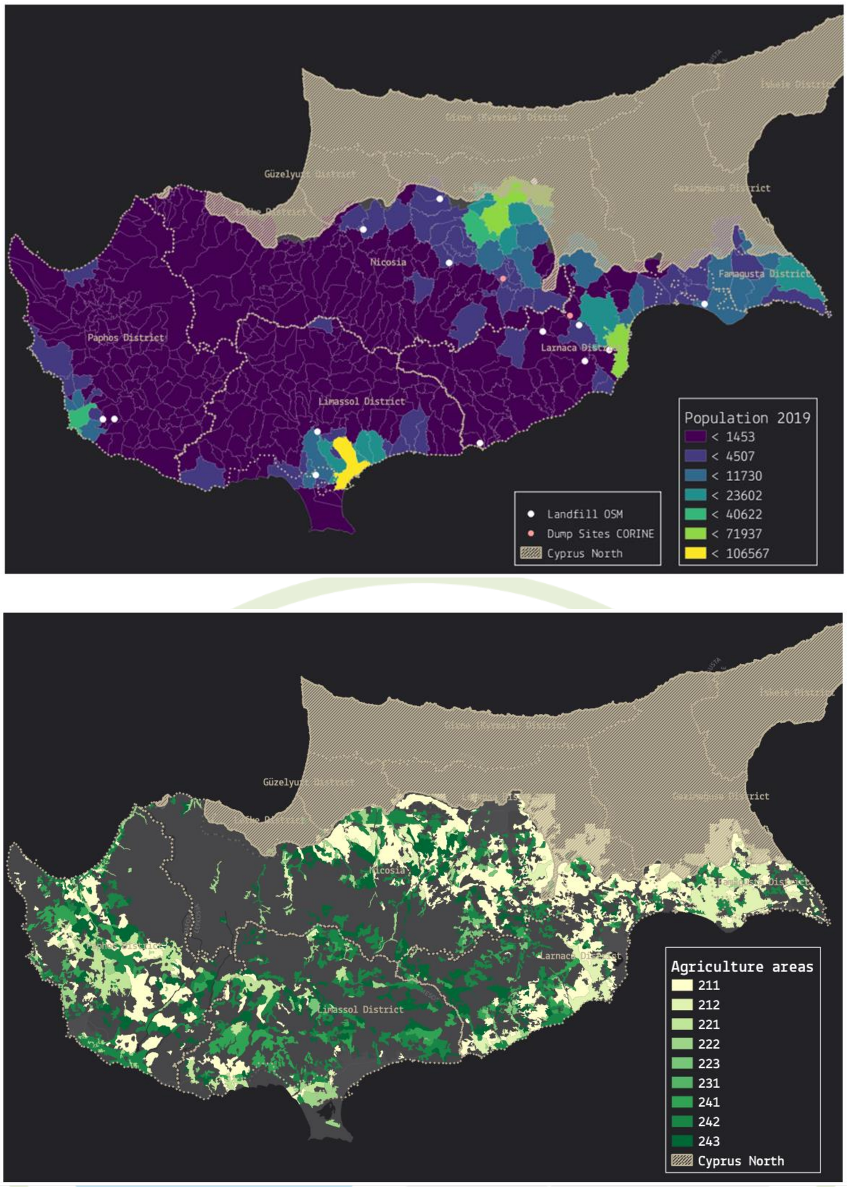


Figure 6. Industrial, commercial units and public facilities (Corine Land Cover 2018) (top), disposal sites and population by commune in Cyprus (middle) and agriculture Areas CORINE in Cyprus (bottom)

The results are summarized in **Figure 7** where the variation in total CO_2 equivalent national emissions from all sectors are depicted from 1990 to 2020 showing the contribution of each sector and the trend reversal noted after 2014 after a period of reduction (2008 to 2013) mostly influenced by economic and financial crisis. The spatial representation of the respective emissions is given in **Figure 8** showing the main emission hot spots over residential and industrial areas.

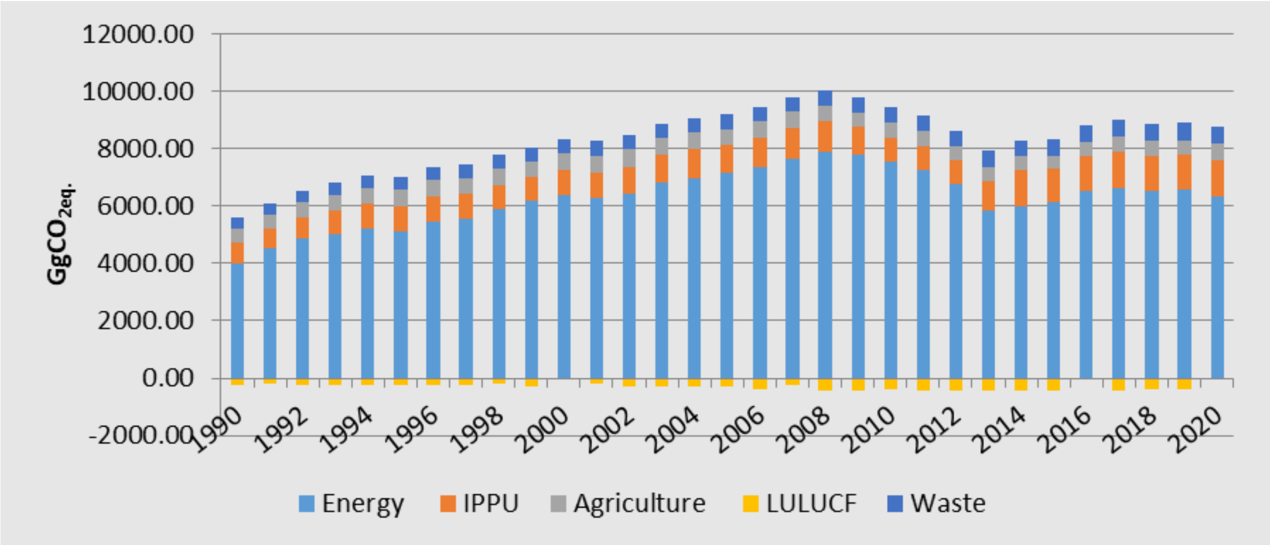


Figure 7. Timeseries of total CO_2 equivalent GHG emissions for Cyprus

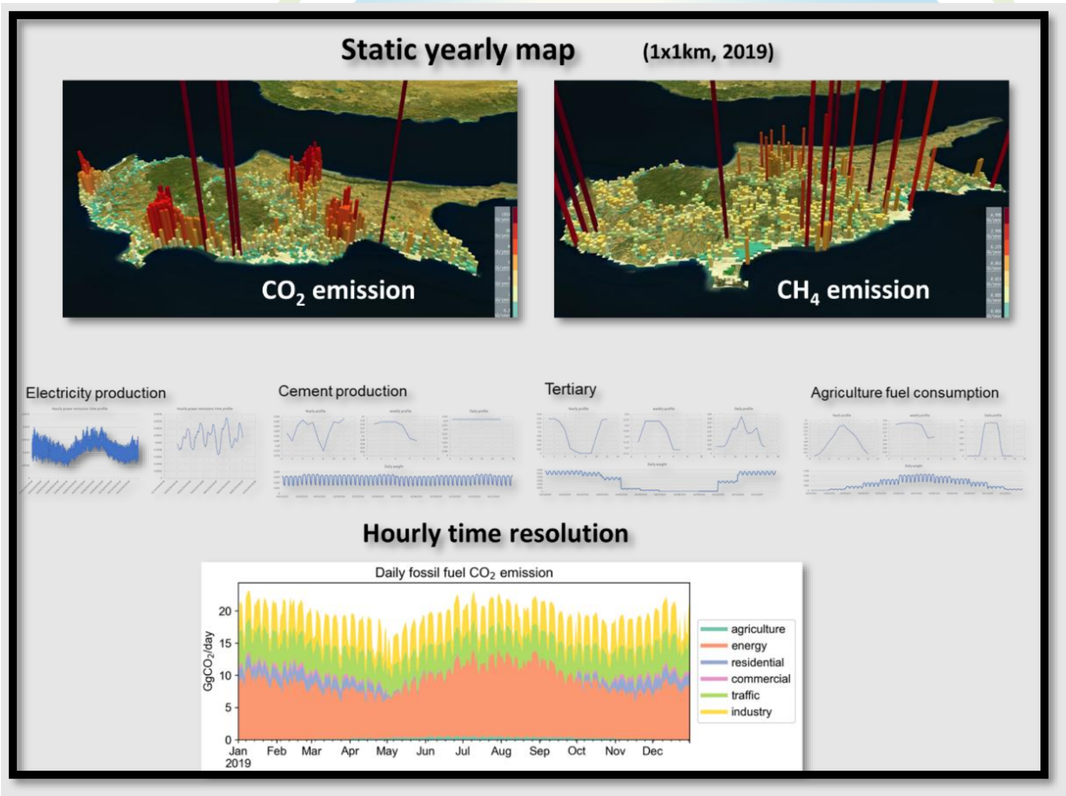


Figure 8. Gridded emission inventory of CO_2 and CH_4 for 2019 and sectoral temporal variations

II.8. Contribution of natural sources on ambient air quality (Directive 2008/50/EC)

CARE-C is drafting every year (since 2015) the annual report on the "origin of airborne particulate matter" in Cyprus submitted to the European Commission via the Department of Labour Inspection (DLI), the governmental body responsible for the continuous monitoring of the concentration of various pollutants in the atmospheric environment as well as with the assessment and management of air quality in Cyprus. The report aims at quantifying the contribution of natural sources to the monitored levels of PM_{10} in Cyprus and for this purpose, data from only two of the nine stations operated by DLI, are considered; the traffic station at Cyprus' capital Nicosia and the regional background station of Agia Marina Xyliatou.

The report is drafted based on the EC directive 1999/30/EK and the contribution of natural sources, namely desert dust and sea salt particles in the case of Cyprus, is calculated following the Directive 2008/50/EC on ambient air quality and cleaner air for Europe. As it is difficult to estimate the contribution of natural sources to the total concentration with sufficient accuracy, the Directive facilitates the analysis and sets the basis for a more harmonized implementation.

The analysis is performed at CARE-C/EOD (Environmental Observation Department) on the weighed mass (at 50% RH) collected on daily resolution PM_{10} samples that have been additionally analyzed for water-soluble ions, bulk carbon (EC and OC), and trace metals at the Environmental Chemistry Laboratory (ECL) of CARE-C. As a measure of quality control, chemical mass closure defined as the mass closure between the sum of major chemical species and the PM_{10} mass concentrations determined from filter weighing, is performed. For each year, 5-day back trajectories starting at noon are calculated daily using the dispersion model HYSPLIT (Stein et al., 2015; Rolph et al., 2017). The trajectories are classified according to their region of origin. The back trajectories deemed as 'clean' are identified as those with no apparent effect of desert dust in the area. Based on this discrimination, the background value for all measurement days is calculated. The difference between the observations and the calculated background is considered to be the transported dust following the methodology described in the work of Escudero et al. (2007) as updated by Querol et al. (2009). The sea salt concentration is calculated considering on one hand Na as being entirely of primary marine origin and on the other that the ionic sea salt fraction is fixed. The assumption is valid. The sea salt concentration can then be calculated according to the Na ratio of sea salt (30.59% by weight) found in the literature.

Currently, Cyprus complies with Directive 2008/50/EC with respect to $PM_{2.5}$. However, the annual PM_{10} legislated limit is frequently exceeded at the traffic station located at the capital as shown in **Figure 9**. Only after subtracting the natural contribution from dust and sea salt particles that the PM_{10} concentration decreases to acceptable levels. The same holds for the number of exceedances with respect to the average daily value of 50 $\mu g/m^3$. Typically, more than double the 35 allowed exceedances per year are identified at the traffic site, the bulk of which is traced back to natural contributions and not taken into account. Even though currently this does not pose an immediate issue, it will be in the future as the limits are expected to be more stringent. If the proposed limits are enforced in 2030, the regional background site in Cyprus will marginally comply with respect to PM_{10} and frequent subtraction of natural sources will be required to do so.

This is not the case for $PM_{2.5}$ where the designated future limit of 10 $\mu g/m^3$, is expected to be violated systematically as the annual average is 14.0±3.6 $\mu g/m^3$ (Pikridas et al., 2018). Aligning with the EU's new air quality standards suggests that urban areas in Cyprus would have to establish air quality plans ahead of 2030. In this direction, we delivered a mitigation plan regarding air pollution in Cyprus, which needs to be refined with respect to each urban area. Provisions on air quality monitoring and assessment should be updated, including new requirements for monitoring pollutants of emerging concern.

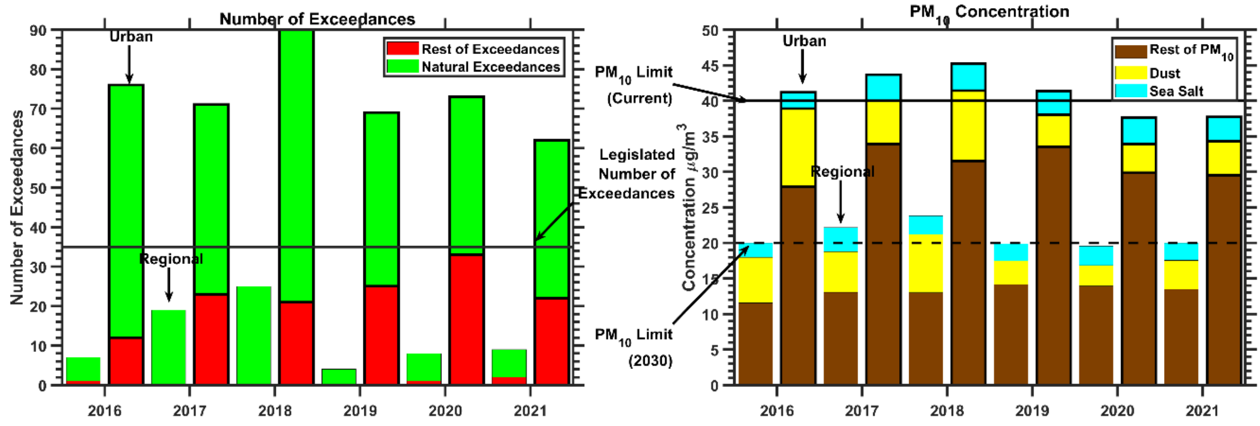


Figure 9. Annual exceedances of the daily PM_{10} limit of 50 μg/m^3 at Nicosia traffic station and the regional background site of Agia Marina Xyliatou (left panel). The exceedances due to natural contribution are shown in green and the rest in red. Annual PM_{10} concentrations at the two sites is also shown (right panel) in brown, with the contribution of dust and sea salt particles in yellow and light blue, respectively depicted.

III. National Action Plan on Climate Change Adaptation

III.1. Policy Background for Climate Change Adaptation

The **National Strategy for Adaptation to Climate Change** (NSACC, Decision no. 82.555 by the Council of Ministers of the Republic of Cyprus on 18/05/2017) with its National Action Plan (NAP), was finalised by the Dept. of Environment (DoE) of the Ministry of Agriculture, Rural Development and the Environment in April 2017 and approved by the Council of Ministers of the Republic of Cyprus on 18 May 2017. It covers geographically the Government-controlled areas of the Republic of Cyprus and addresses adaptation in the following eleven (11) impact sectors (section Four, pages 17-33 of the NSACC document; pages 1-14 of the NAP document):

1. Water resources;
2. Soils;
3. Coastal areas;
4. Biodiversity;
5. Agriculture;
6. Forests;
7. Fisheries and aquaculture;
8. Public health;
9. Energy;
10. Tourism;
11. Infrastructure.

The implementation of the NAP is expected to shield the environment and society from the adverse impacts of climate change in the long-term, as it foresees a total of 57 measures for the 11 impact sectors listed above.
Within its mandate as the competent authority for the NSACC, DoE interacts with all Government Departments to obtain updates on the stage of planned or already executed implementation for all NAP measures. There is a constellation of Government Departments and respective responses updating on implementation of all NAP measures with a very variable degree of NAP implementation in terms of perception, cross-Department coordination, planning, financing and execution. Hence, there is a need of an integrated NAP coordination and implementation effort. Another challenge of the current NAP content is the diversity and the overlap of the types of actions contained in the 55 measures: 10 regulation, 5 construction, 10 research study, 5 policy update/action plan, 10 monitoring, 10 intervention 10 dissemination promotion.

III.2. Recommendation for implementing the National Action Plan

A set of relevant actions were considered to address priority climate change impacts/risks (some of them cross-sectoral) addressing specific NAP measures, prepared by CyI and proposed to the DoE for consideration and implementation. In particular, the recommendation for implementing the National Action Plan addresses adaptation measures covering most of the NAP sectors and primarily agriculture, forest, biodiversity, soils, public health and water. In addition, modelling and information systems for extreme events (heat waves, droughts, ozone exceedances, dust transfer, vector-borne disease outbreaks) are proposed to be developed and applied. The overarching objectives of the actions are:

- Implementation of the NAP, addressing explicitly several of its measures and fostering its total service by accounting for all 55 of them;
- Coordination and enhancement of the implementation of the NAP measures;
- Building the capacity of the NAP government participants;

- Establishment of permanent monitoring and replication mechanisms;
- Direct intervention in certain climate change impact sectors to prevent, control and combat related risks;
- Local level amelioration of climate resilience with pilots in three regions of Cyprus;
- Involvement of the relevant stakeholders for the awareness of impacts and adaptation actions

The following set of actions can form a basis for a 5-year implementation of the NAP (also shown in **Figure 10**):

○ **Preparatory PA1**: the NAP of Cyprus will be updated with new information that has arisen since its drafting and the progress made so far on the implementation of the adaptation measures foreseen in the NAP will be recorded

○ **Preparatory PA2**: identification of the stakeholders that will either be involved or can influence the planned activities, to produce a Stakeholder Engagement Plan on how best to be involved in the initiative for mutual benefit

○ **Fostering Action (FA1):** an efficient Monitoring, Reporting and Assessment (MRA) system that will include a monitoring protocol, clear-cut indicators that would be tailor-maid for national scale use, a robust methodology to calculate the indicators, as well as an online Monitoring Platform (MP) that will facilitate all data and results. Indicators will consider the spatial specificity and will be divided into three main categories related to actions' implementation, the effectiveness of the vulnerability and adaptation measures (e.g. increase water availability, decrease water demand) and the stakeholders' engagement and capacity building. All the indicators will be calculated before (baseline scenario) and during the implementation phase.

○ **Fostering Action (FA2):** this is a permanent coordination and activation effort which will ensure that all NAP measures corresponding to other Government Departments or Complementary Actions are implemented with the necessary speed and dedication. DoE would establish efficient channels of communication so that all NAP measure efforts are in sync, for example with the launch of recurring 4-year NAP Implementation Roadmap.

○ **Implementation Action (IA1):** includes ground intervention activities for risk monitoring, prevention, control and combat by the relevant government departments on agriculture/crops and forest ecosystems (reforestation and fires).

○ **Implementation Action (IA2):** combines field observations, modelling and analysis for key sectors, carried out by CYI, to produce assessments for the sectors of energy and soil and prepare relevant policy briefs and management plans that directly fulfil the respective NAP measures that address. These include energy system simulations to ascertain the optimum way of deploying additional renewables, building energy performance simulations, optimal technologies for heating/cooling in the tourist sector and the production of a sustainable land use map, based on erosion assessment.

○ **Implementation Action (IA3):** adds to the background knowledge of physical and ecological systems with theoretical and applied scientific research, as it is explicitly stated in the NAP measures of some impact sectors, such as agriculture, biodiversity and the built environment.\

○ **Implementation Action (IA4):** provides a local level and stakeholder dimension to the NAP implementation effort, by working with municipalities and communities in key regions of Cyprus, to provide climate adaptive and sustainable solutions. These will establish pilot interventions in urban areas that respond to increasing climate change related risks such as flooding, riverbed erosion, urban heat, improve breeding on terraces to exploit Troodos biodiversity and local farmer knowledge towards more climate-adapted varieties and optimize irrigation water use efficiency and product value of drought- and heath-tolerant crops.

○ **Capacity building (CB):** builds capacity in Cyprus for climate change adaptation (CCA) covering the whole spectrum of capacity building needs and target audiences (i.e. government departments, municipalities, professional groups, citizens). These include seminars to build capacities of the NAP government stakeholders (the competent Government authorities assigned for the NAP implementation and other related participants) and urban municipalities and help them integrate climate change issues in daily operations and administrative planning, to establish networks/bridges of cooperation among the relevant authorities and stakeholders and to identify opportunities for good practice sharing.

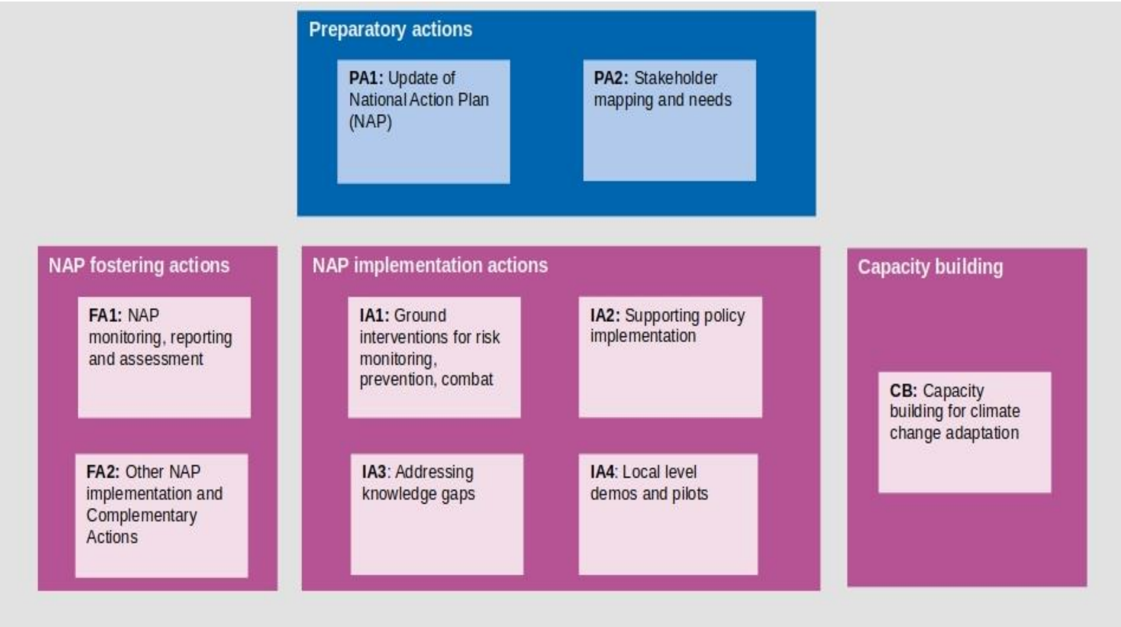


Figure 10. Structure of recommended actions for a revised Cyprus National Action Plan (NAP) on Climate Change Adaptation

III.3. Eastern Mediterranean & Middle East Climate Change Initiative (EMME-CCI)

As a follow-up of the successful International Conference on Climate Change organized by the Cyprus Institute in 2018 (EMME-CARE, Phase I**), the Eastern Mediterranean and Middle East Climate Change Initiative (EMME-CCI)** was initiated in March 2019 by H.E. the president of the Republic of Cyprus and has matured into an ambitious scheme striving to coordinate a concerted effort by the countries of the region to address the climate crisis.

An evolving **Regional Action Plan** for the countries of the EMME, and an organizational structure to underpin its efforts, have been tentatively agreed upon within the framework of two regional Ministerial Meetings that took place in February and June 2022 and are expected to be formalized after the COP27 (November 2022). The EMME Regional Action Plan is a set of proposed projects and services, that was put together based on the work of thirteen (13) thematic Task Forces comprised of over 240 scientists under the coordination of *The Cyprus Institute*. It places emphasis on transboundary measures aimed at ameliorating regional climate change effects and advancing relevant mitigation actions, in line with the Paris Agreement. The EMME-CCI was inaugurated by the heads of EMME states in Sharm el-Sheikh at COP27 (November 2022) at the invitation of T.E. presidents A.F. El-Sisi of Egypt and N. Anastasiades of Cyprus.

Within this Initiative, CARE-C researchers led the Task Force on the Physical Basis of Climate Change, as well as the Task Force on Health. Our findings, together with those of all other Task Forces, provided the scientific evidence and basis for the development of the EMME Regional Action Plan. The full reports and peer-reviewed articles published by these Task Forces are available at https://emme-cci.org/scientific-task-forces/

III.3.1. Task Force on the Physical Basis of Climate Change

Within the EMME-CCI Initiative, CARE-C researchers led the Task Force on the Physical Basis of Climate Change. Some aspects that are being addressed are:

1) Global and EMME climate change (also greenhouse gas emissions, global vs. regional);
2) Past climate: Variability in the last 1000 to 2000 years (temperature, precipitation, droughts, …);
3) Changes in the last 120 year (temperature, precipitation, extremes);
4) Recent changes (mean climate and extremes): Climatology maps, trends; 5) 21st century scenario projections (mean climate and extremes);
6) Challenges and recommendations for critical sectors (health, energy, agriculture, urban, tourism);
7) Data/model uncertainties/needs, research recommendations;
8) Outlook for regional cooperation;

Scientific results of these Task Force were presented in the High Impact Journal "Review of Geophysics" in 2022 (Zittis et al., 2022). A summary of the main findings of the Task Force on the Physical Basis of Climate Change is presented below:

- The Eastern Mediterranean and Middle East (EMME) region is warming almost two times faster than the global average and more rapidly than most other inhabited parts of the world, especially during summer.
- Over the past hundred years, precipitation variability in the region was high, with pronounced fluctuations between drier and wetter periods. In recent decades, there are indications of a general decrease in precipitation and a transition to a drier climate.
- Greenhouse gas emissions in the EMME increased fivefold over the past several decades. Today, regional emissions are comparable to those of the European Union and India, and a strong upward trend suggests that the region will shortly become one of the world's dominant emitters.
- For the rest of the 21st century, climate projections indicate an overall warming of up to 5ºC, strongest in the summer. Precipitation will likely decrease by up to 20-30% in many regions, particularly in the eastern Mediterranean.
- Business-as-usual pathways for the future imply a northward expansion of arid climate zones at the expense of more temperate Mediterranean zones. Mountainous climate zones with snow will likely diminish by the end of the century.
- A strong increase in both the intensity and duration of heatwaves is expected. This is a robust outcome of all climate models and emission scenarios. Depending on the scenario, heat extremes have the potential to disrupt society.
- The combination of precipitation decreases and strong warming will likely contribute to severe meteorological and hydrological droughts. In combination with a rapid growth in water demand, significant water shortages may be expected.
- The frequency, duration and severity of dust storms, which are common natural hazards across the region, are expected to increase under a warmer climate, which may affect atmospheric circulation, ecosystems, agriculture and human health.
- Virtually all socio-economic sectors will be critically affected by the projected changes. Human health and well-being will be directly affected, especially among underprivileged people, the elderly, children and pregnant women.

III.3.1. Task Force on the Effects of Climate Change on Health

The main findings of this Task Force are summarized below (a more detailed description of the effects of climate change on human health is presented in deliverable D7.4):

- Susceptibility to climate change is influenced by biological, ecological and socio-political factors. In the EMME, this vulnerability is heightened by extreme climatic conditions (with several areas already approaching thresholds for human adaptability), high urbanisation rates, rapidly expanding population, high prevalence of chronic diseases in the population, poor or aging health infrastructures, political and armed conflicts in the region, high rates of population displacement.
- The EMME is one of the world's most vulnerable regions to heat exposure, in part due to an ageing population, as well as the amplification of heat effects in urban areas due to the presence of "urban heat islands".
- Under a business-as-usual emissions scenario, by the year 2100 parts of EMME could reach environmental temperatures surpassing the threshold for the human body's physiological adaptability.
- EMME is among the regions with the least water availability in the world, encompassing at least nine countries which experience absolute water scarcity.
- The main sources of air pollution in the region are fossil fuel burning, urbanization (heat islands) and wildfires.
- Airborne dust is a major air pollutant in the EMME. The Sahara, the Arabian deserts and the Sistan region are major sources of airborne dust in this region.
- The epidemiological landscape of vector-borne diseases is heavily influenced by climatic and socio-economic factors, including heat, precipitation, humidity, wind, land use, housing conditions and basic service availability, among others.
- Vector-borne diseases relevant to the EMME include viral diseases (dengue, chikungunya, West Nile virus, etc), leishmaniasis and malaria.
- Climate change contributes to population displacement (forced migration) through an increased intensity and frequency of extreme weather events, loss of land to sea-level rise and water scarcity, deterioration of life-sustaining ecosystems, and by influencing outcomes of conflicts caused by economic, social or political factors. The EMME is one of the world's largest origins and hosts of displaced populations, and therefore the health effects associated with displaced populations should be carefully addressed in the region.

III.4. Contribution to the Cyprus 8th National Communication and 5th Biennial Report

As the country's leading research organization in climate and atmospheric sciences, CARE-C supports governmental departments of the Republic of Cyprus with data, analysis tools, and expert advice when it comes to future climate projections and climate change impacts in Cyprus and the region.

Recently, CARE-C has been consulted the Department of Environment, Ministry of Agriculture, Rural Development and the Environment through an extensive contribution to the Cyprus 2022 8th National Communication (NC8) and 5th Biennial Report (BR) for the United Nations Framework Convention on Climate Change – UNFCCC (https://unfccc.int/documents/629351). Parties included in Annex I to the Convention, including those that are also Parties to the Kyoto Protocol, shall submit their National Communications (NCs) to the secretariat every four years (decision 2/CP.17). The eighth national communication (NC8) for the Republic of Cyprus was submitted in December 2022. Our contribution was based on recent studies, several of them supported by the EMME-CARE project and research conducted in the different departments of CARE-C. In particular, we led the writing of Section 6:

"Vulnerability assessment, climate change impacts and adaptation measures". This included an extensive literature review on the climate change impacts on Cyprus and an analysis of state-of-the-art climate projections such as the multi-model and multi-domain ensemble presented in Zittis et al. (2022). An example of this analysis is presented in **Figure 11**, which depicts the expected range of temperature and precipitation projections for the island.

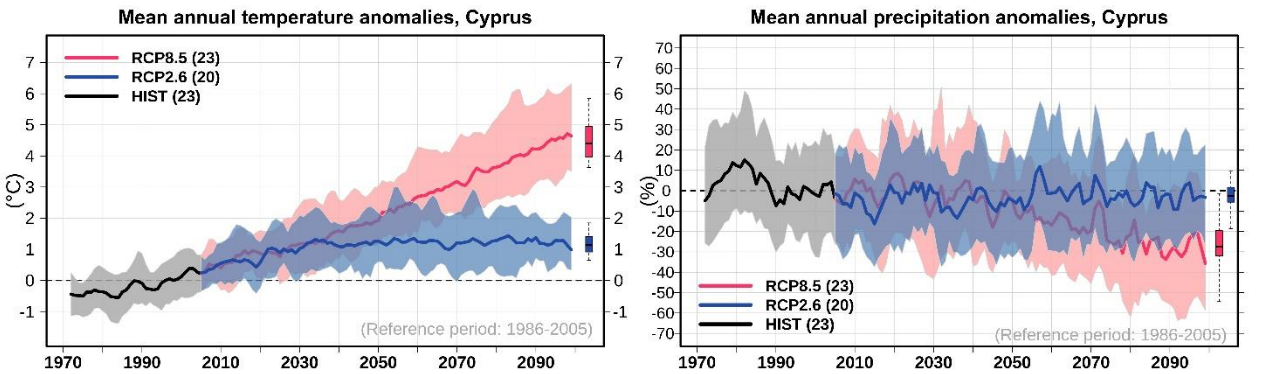


Figure 11. Projections of mean annual temperature (left panel) and precipitation (right panel) anomalies for Cyprus based on the CORDEX-CORE ensemble (see Zittis et al., 2022).

In this report, we highlighted that Cyprus, and the rest of the Eastern Mediterranean is warming substantially faster than the rest global average rates. A future scenario close to meeting the Paris Agreement's main targets (e.g., RCP2.6) implies that regional warming will continue at current rates in this decade and then will be stabilized to near 1 °C with respect to the end of the previous century or at about 2 °C since the preindustrial (**Figure 11 – left panel**). On the contrary, under a business-as-usual pathway (e.g., RCP8.5), the observed mean warming will continue almost linearly for the rest of the century and will likely reach 4.5 °C. This warming is projected to be more pronounced in the inland parts of the island, including the capital city of Nicosia and is expected to be stronger during the summer months. Regarding precipitation (**Figure 11 right panel**), the interannual variability and model spread are significantly higher. Nevertheless, under pathway RCP8.5, the annual rainfall will be decreased by 20-30% of the reference values. This is expected to be most significant during the wet part of the year, which is also more critical for replenishing the water resources of the island. For RCP2.6, the expected precipitation changes are less pronounced and comparable to the natural climate variability.

III.5. Contribution to the update of the national Flood Risk Assessment

Our modeling methodologies and tools, including high-resolution projections optimized for the eastern Mediterranean environment and Cyprus (e.g., Zittis et al., 2020), have been widely used for supporting the Water Development Department (WDD) on revisiting its Flood Risk Assessment for Cyprus. In more detail, compliance with Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (https://www.eea.europa.eu/policy-documents/directive-2007-60-ec-of) requires an update of the national Flood Risk Assessment, considering the impacts of climate change and the potential adverse consequences of future floods for human health, the environment, cultural heritage and economic activity (Articles 4 and 5).

CARE-C provided projections and analyses on how mean climate conditions (e.g., temperature and precipitation) might evolve in the future. In addition, we considered the effects of climate change on several characteristics of extreme rainfall (intensity, duration, etc.). This assessment report was released by the Department of Environment in December 2020. An example is presented in **Figure 12**, which represents future climate projections for the maximum 5-day precipitation under a business-as-usual pathway.

While the mean conditions in the region and Cyprus will likely become drier, the absolute most extreme cases are expected to be of unprecedented magnitude, while this type of event can occur at any point in time during the current century posing additional challenges in water resources and flood management (Zittis et al., 2020; Zittis et al., 2021).

Such extremes can be significantly underestimated when not considering the impact of climate change and when calculated by more traditional approaches that are currently used, e.g., in hydrological applications (e.g., flood risk assessments) or during the design of infrastructure. In the example of Figure 13, we compare the 1-in-100-years extreme daily rainfall for Nicosia derived by 50 years of historical data from the period 1951-2000 (black points), with the projected 1-in-100-years extreme daily rainfall derived from 21st century projections, considering the effect of climate change (red point). For this particular climate model, the conventional statistical approach underestimates the most extreme event by about 40% or 50 mm/day.

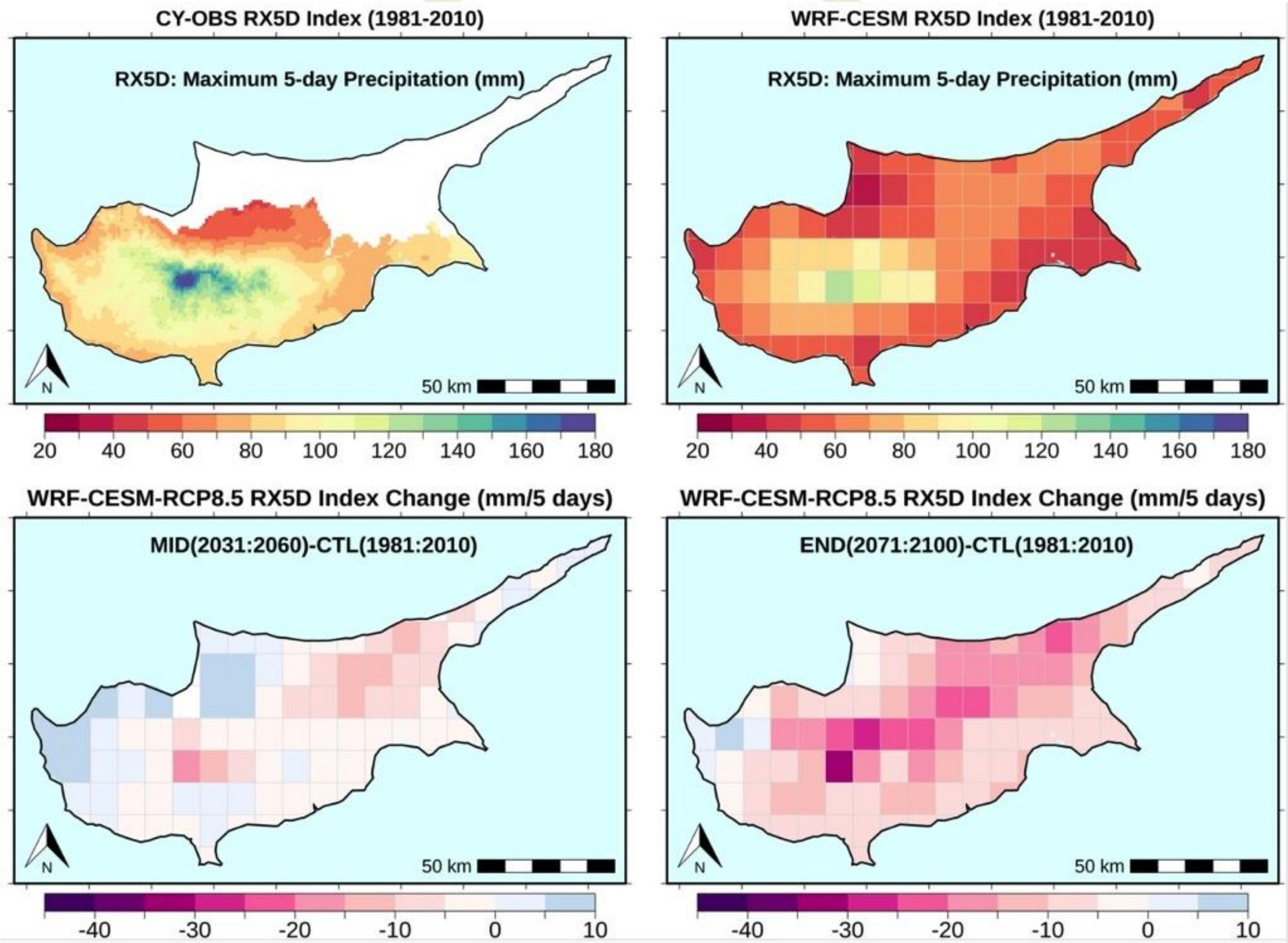


Figure 12. Observed (top left) and simulated (top right) maximum 5-day precipitation per year (RX5D) for the period 1981 to 2010 and projected changes for the middle (bottom left) and end of the 21st century (bottom right). century (bottom right).

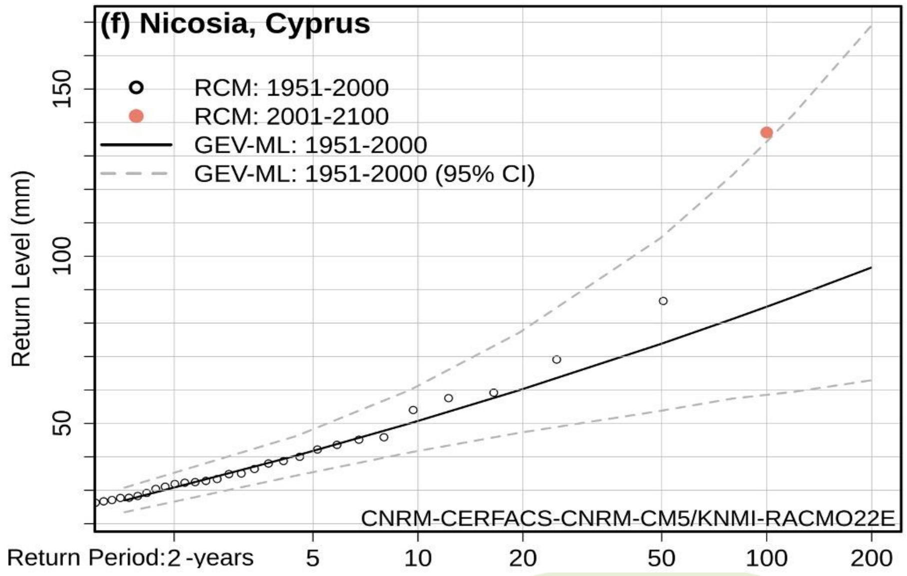


Figure 13. Extreme daily precipitation quantiles and 95% confidence intervals based on the GEV-ML method and the historical simulations for 1951–2000 in Nicosia. The 100-year return period daily precipitation based on the 21st century projections are also shown (red point).

III.6. GHG mitigation to limit global warming under the Paris Agreement

Countries pledge mitigation of greenhouse gases (GHGs) in various forms including near-term reduction targets for 2030, long-term net-zero emissions by mid-century and targets for reductions of methane emissions, towards limiting global warming to 2°C while pursuing 1.5°C, as stipulated in the Paris Agreement. These undergo regular revisions to strengthen the ambition, with the latest set of revisions occurring during the 26th and 27th Conferences of Parties (COP26 and COP27). As of December 2022, 169 countries have near-term targets (UNFCCC, 2023b), 61 have long-term targets to become carbon neutral (UNFCCC, 2023a) and 150 nations have pledged to reduce their methane emissions by up to 30% by 2030 (CCAC, 2023). However, countries would still require further significant upgrades to meet the goal of the Paris Agreement (Climate Action Tracker, 2022; Fu et al., 2022; Geiges et al., 2020; Meinshausen et al., 2022; Ou et al., 2021; UNEP, 2022).

A suite of emissions pathways with more ambitious targets than current pledges was studied. It includes a) increasing the near-term targets for 2030, b) advancing years for achieving net-zero emissions, c) increasing the scope of the Global Methane Pledge and d) potential actions in response to the Glasgow declaration on ending deforestation. Modelling future emissions trajectories of CO_2, CH_4 and N_2O from 2019 to 2100 based on the latest updates of national pledges including the near-term targets in the NDCs, long-term strategies to attain net-zero emissions, global methane pledge and stopping the loss of forest cover, we show that under the current levels of these national pledges, the total CO_2-eq emissions are projected to peak between 2025-2030.

As a result of relatively stringent near-term and earlier achievement of net-zero emissions by developed nations, the future emissions budget (2020-2100) is largely dominated by heavily industrialized and populated countries among which developing countries such as EMME nations. Therefore, subject to the full realisation of the declared targets, there is likely to be a shift in responsibility from developed countries (which dominated the historical GHG budget from 1990-2019) towards developing countries. High-ambition scenarios explored in this study showed that upgrading the current levels of pledges can avoid up to 0.7°C (**Figure 14**).

Furthermore, over 100 countries currently do not have long-term reduction strategies, particularly in the EMME region. Thus, if they introduce moderately ambitious targets to achieve net-zero CO_2 emissions post mid-century, this could prevent a temperature increase of 0.22 °C and stabilize the rise in temperature change post 2050. It has been highlighted that EMME nations can play a significant role and can provide the maximum benefit towards this goal if they introduce the moderately ambitious target to achieve net-zero CO_2 emissions by 2070.

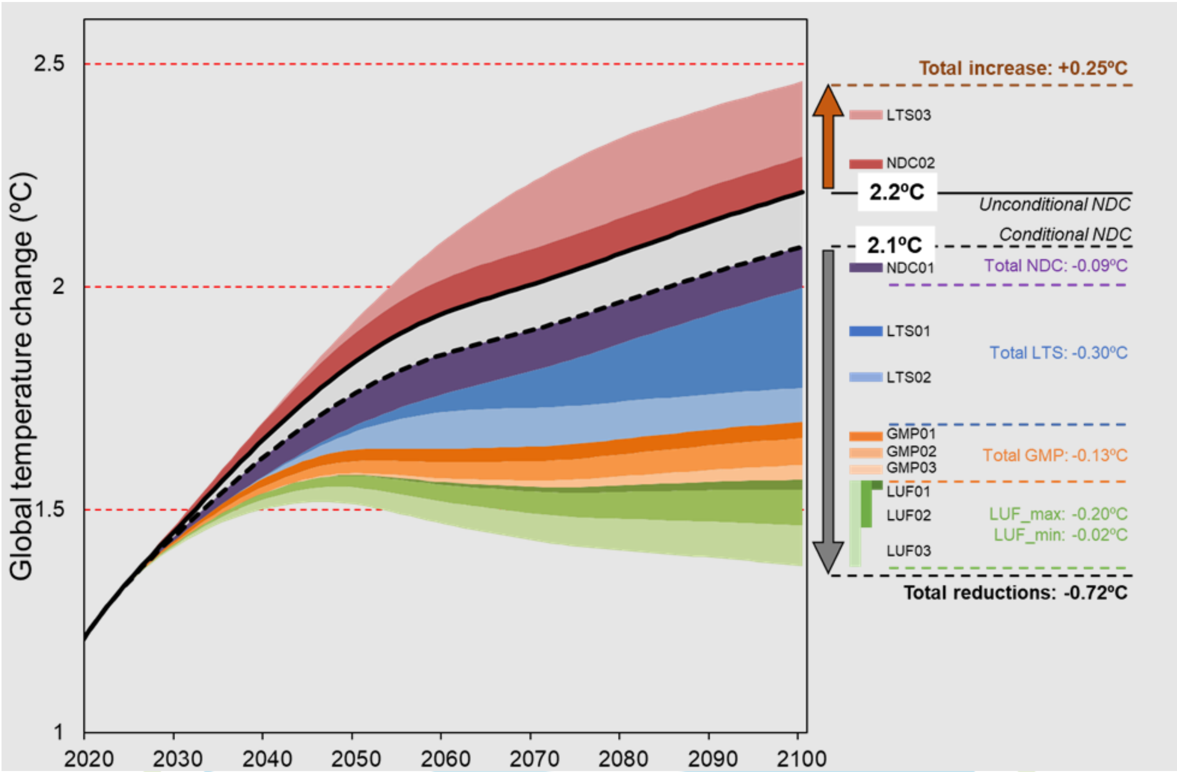


Figure 14. Implications on global temperature change from alteration of current national pledges.

III.7. GHG Inventory and Projections: CARE-C support to the design of National Action Plans and Measures Efficiency

CARE-C supports the Department of Environment (DoE) in the calculation and compilation of the Greenhouse Gas Inventory and Projections, in order to fulfil the obligations of Cyprus, jointly with other EU Member States, under the Kyoto Protocol, for its second commitment period. The Union, its Member States Cyprus and Iceland agreed to a quantified emission reduction commitment that limits their average annual emissions of greenhouse gases during the second commitment period to 80 % of the sum of their base year emissions, which is reflected in the Doha Amendment.

The current national goal, submitted in December 2020 within the framework of the Paris Agreement, is to reduce emissions by at least 55% below 1990 levels by 2030 including LULUCF (Land Use and Land Use Change and Forestry). Moreover, the European Council (heads of state or government of the EU Member States, the European Council President and the President of the European Commission) endorsed the objective of achieving a climate-neutral EU by 2050, in line with the Paris Agreement. Cyprus is also obligated to report national projections of anthropogenic greenhouse gas emissions under Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action.

To do so, the CARE-C is responsible for the calculation and compilation of the NIR (National Inventory Report) for the year X-2 which is submitted to the EU and to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). CARE-C is also responsible for the calculation of GHG Projections up to 2050 using as a base the inventory for the historical years, and taking into consideration Policies and Mitigation Actions (PaMs) given by the DoE into three different scenarios: BaU (Business as Usual), WEM (with existing measures) and WAM (with additional measures). If the current measures are not enough to achieve the goals, the CARE-C team follows the instructions of the DoE to assess the impact of new measures in the projections, and the DoE presents them at the Council of Ministries, in order to decide which new measures will be included in the National Energy and Climate Plan (NECP).

The contribution of CARE-C has been continuously important to the design of national action plans, with peak involvement in 2022-2023. The projection calculations and two chapters, one on policy and measures and another on projections, were prepared by CARE-C under the auspices of the DoE and submitted under the 8th National Communication and 5th Biennial Review to the UNFCCC in December 2022. This publication is available on the UNFCCC website, at https://unfccc.int/NC8. The base year for these calculations was inventory year 2020.

However, due to the COVID pandemic and its impact on emissions, it was deemed necessary to reassess the estimations by changing the base year to 2021 so that the projections are more realistic. The impact of different PaMs has been assessed in all sectors. New energy scenarios have been tested several times for all the cases (BaU, WEM, WAM) in order to achieve the best results with feasible and objective measures, with most new updates being in the WAM scenario, to be able to propose new additional measures that can be adopted. The main measures taken in Energy have to do with the promotion of renewable energy sources (RES), the promotion of energy efficiency and the introduction of natural gas in the energy market of Cyprus through the implementation of the Project "LNG Import Terminal". In **Figure 15**, the evolution of RES share is shown for each scenario.

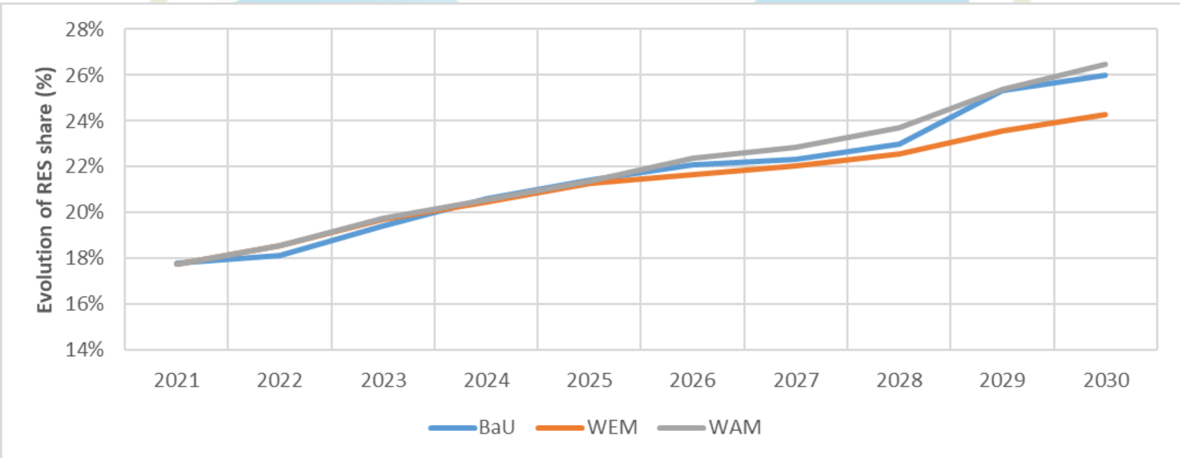


Figure 15. Evolution of RES share(%), BaU, WEM and WAM

More measures have been suggested by the CARE-C team, such as a working from home plan, since it was proved that during the COVID-19 pandemic that such a measure can have a large impact on emissions. However, this measure has not been assessed yet in the official calculations. Our preliminary results are however shown here as a case-study.

In detail, an assessment of the potential impacts of working from home as an emissions reduction measure in Cyprus was performed by CARE-C emissions team. In April 2022, the European Commission and the International Energy Agency noted that while commuting accounts for one -fourth of the oil used by cars in the EU, more than one-third of jobs could be performed from home, with significant impacts if applied three days a week. Based on the following background landscape:

- EU Target of 55% GHG Reductions by 2030
- Cyprus: 4th Highest GHG/Capita in EU-27 (2019 & 2020)
- Road transport = 25% of emissions
- 5th Highest Number of Cars/Capita in EU-27 (2020)
- Air Pollutant Reduction Targets

we addressed the question “How would scaling RePowerEU reductions to Cyprus impact greenhouse gas and air pollutant emissions relative to other projection measures?”.

It has been found that for each of the scenarios summarized in Figure 16 there is an additional reduction that can be achieved through the implementation of this policy (9-19%). Comparing the potential reduction from decreased commuting to all other quantified estimates of projected pollutant Reduction Measures in 2025 shows that this approach is effective and easy to implement with the majority of regions affected being within heavily populated areas like cities.

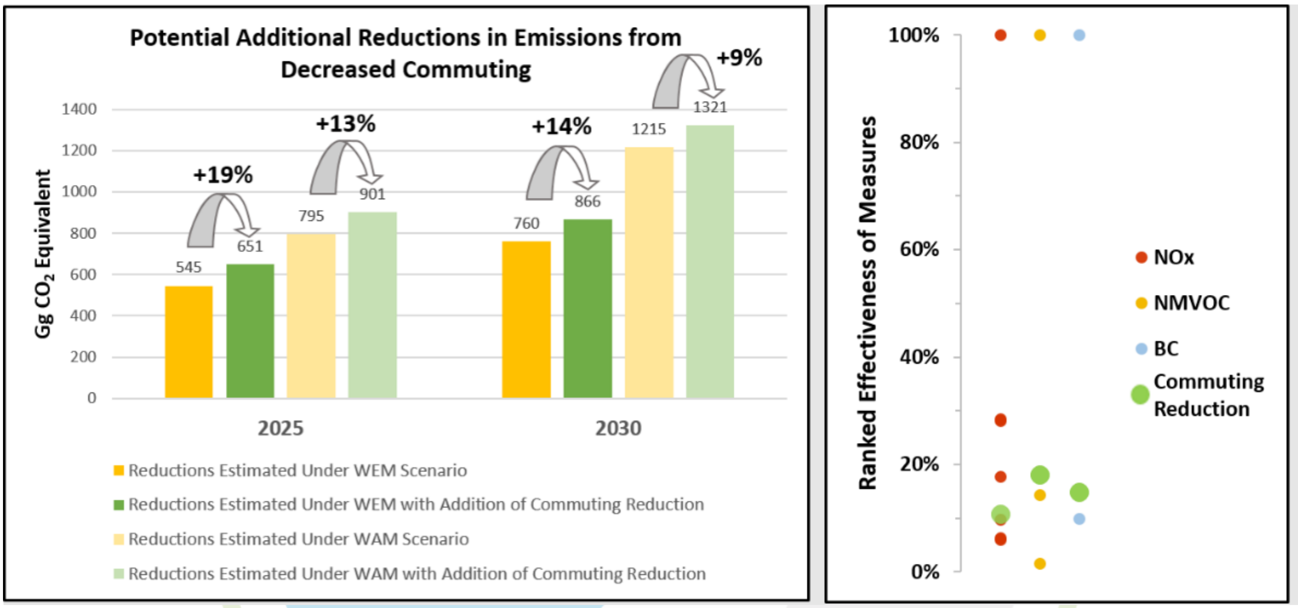


Figure 16. Potential Additional Reductions in Emissions from Decreased Commuting (left) and comparison to all other quantified estimates of Projected Pollutant Reduction Measures in 2025 (right).

Other measures and policies are also taken into consideration in the calculations. Some examples are the preparation of the proper recovery system for F-gases in equipment in the Industry sector, promotion of anaerobic digestion for the treatment and management of animal waste; promotion of anaerobic digestion in existing biogas plants; encouragement of new biogas plants to exploit organic waste from livestock breeding in the Agriculture sector and finally, reduction of the amount of waste that are sent to solid waste disposal sites, reduction of the amount of organics going to landfills, promotion of alternatives for the treatment of the organic fraction of solid waste (anaerobic digestion) and biogas recovery from old landfills in the waste sector.

In May 2023, a UNFCCC in-country review for the GHG Inventory and Projections took place at the DoE premises and the <u>CyI team presented the work carried out in the last 4 years for the GHG inventory and for the last year for the Projections, vital parts of EMME-CARE project and its goals</u>. The comments of the review committee were taken into consideration and more updates and improvements were implemented. The projections were then resubmitted based on the recommendations of the review committee. In addition, an update in the methodology of how reductions are calculated allows for a more accurate examination of the impact of each PaM, which will help in the continued evaluation of the effectiveness of the measures over time.

As part of the development of the draft of the updated National Energy and Climate Plan for Cyprus, new WEM and WAM scenarios were issued by the energy team, along with additional PaMs for the WAM scenario from the DoE and assessed by CARE-C emissions team.

Figure 17 shows the three scenarios BaU, WEM and WAM given all updates suggested by the DoE. The four new PaMs result in greater reductions in total emissions for the Energy, IPPU, and Waste sectors. Biogas recovery from landfills is increased in the waste sector, while recovery of F-gases is increased in IPPU, with two policies and measures introduced in manufacturing industries and construction. New emission scenarios were calculated to reflect these changes, in order to quantify them for their incorporation into the NECP development process. They will be presented by the DoE in the next ministerial meetings (2023) for final approval.

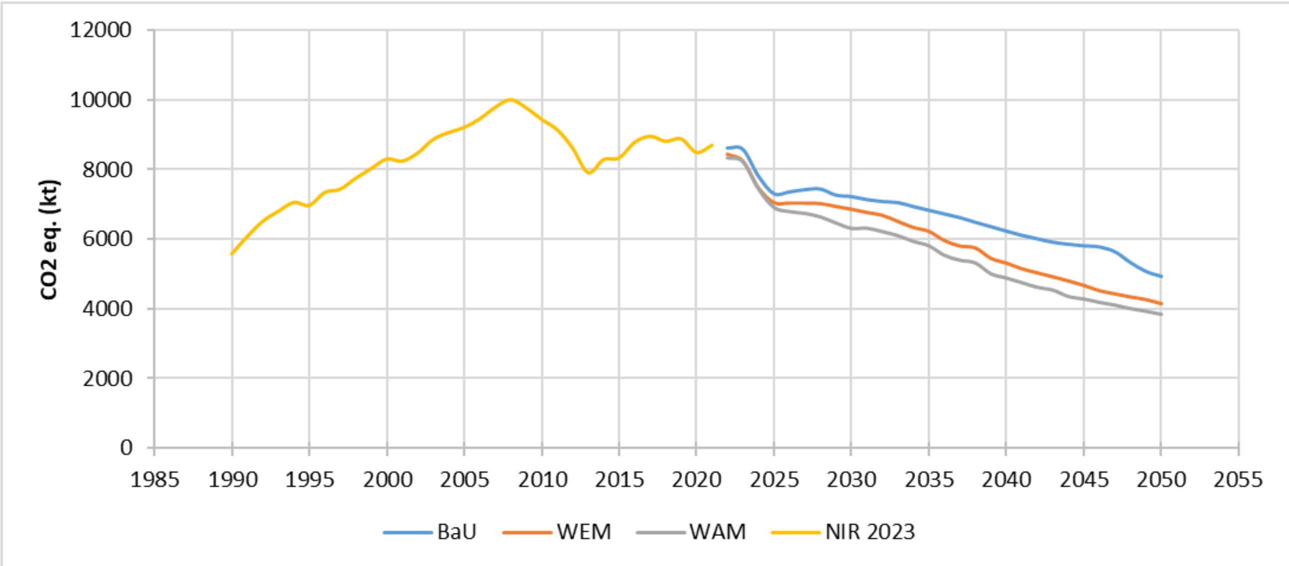


Figure 17: BaU , WEM and WAM latest projections

III.10. Competitive Projects supporting National Action Plan

Below we provide a list of projects, nationally and internationally funded, whose objectives and structure were formulated around the EMME-CARE needs and/or contributed to its goals:

- LIFE-SIRIUS: A System for Integrated Environmental Information in Urban areas - LIFE Programme European Union project LIFE21-GIE-EL-LIFE-SIRIUS/10107436, https://lifesirius.eu/
- ACCEPT: Assessment of Climate Change Effects on Pollution Transport in Cyprus project, EEA AND NORWAY GRANTS, https://accept.cyi.ac.cy/
- AQ-SERVE: Air Quality Services for cleaner air in Cyprus, Integrated Projects, The Research Promotion Foundation Programmes for Research, Technological Development and Innovation, RESTART 2016 – 2020, https://aqserve-project.com/
- Boost projects: Aria Tech project on air pollutant emission fluxes over Cyprus and Origins.Earth project that aims at designing a monitoring network for greenhouse gases over Cyprus

- World Emissions: ESA funded World Emissions project that aims to provide an enhanced global emission monitoring service by developing top-down emission estimates based on satellite data, https://www.world-emission.com/
- CoCO2: EU-funded project (under Grant Agreement 958927) for the development of a Prototype System for a Copernicus CO2 Service including 25 partners from 14 European countries and coordinated by the European Center for Medium-range Weather Forecasts (ECMWF), https://coco2-project.eu/
- AVENGERS: Attributing and Verifying European and National Greenhouse Gas and Aerosol Emissions and Reconciliation with Statistical Bottom-up Estimates, Research and Innovation project funded under the Horizon Europe programme of the European Union call on "Climate sciences and responses (HORIZON-CL5-2022-D1-02)", https://avengers-project.eu/

IV. Future plans

- **Compliance with future EC Air Quality Directive:** There are a series of new pollutants, called emerging pollutants, that are expected to be added to the list of those currently regulated. These are black carbon, gas phase ammonia, lung deposited surface area calculated via particle number size distributions, ultrafine particle number concentrations and reactive oxygen species among others. Several of these emerging pollutants are already being monitored at the CARE-C "Cyprus Atmospheric Observatory" (CAO) at Agia Marina Xyliatou, being mandatory for the ACTRIS network, which also sets the guidelines for sampling. As a result, CARE-C has accumulated know-how that can be transferred to government agencies upon request and share the measurements already conducted to formulate a historical database.
- **Preparation of air pollutant and greenhouse gas emission reports:** CARE-C emissions team will continue to contribute to the preparation of the annual national inventories of greenhouse gas emissions and air pollutants for the national agencies (DLI and DoE) at annual frequency by incorporating also scientific components derived from the relevant research at the center that focuses on country-based characteristics of emission factors and sectoral peculiarities. Similarly, CARE-C will provide updated estimates for the projected emissions up to 2050 taking into consideration Policies and Mitigation Actions with various combination of measures accounting for their feasibility and efficiency.
- **Support on strategy to achieve GHG emission reduction targets:** Continue support to the Department of Environment (DoE) in the calculation and compilation of the Greenhouse Gas Inventory and Projections, in order to fulfil the obligations of Cyprus, jointly with other EU Member States, under the Kyoto Protocol, for its second commitment period. CARE-C undertakes the calculation and compilation of the NIR (National Inventory Report) for the year X-2 which is submitted to the EU and to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). CARE-C is also responsible for the calculation of GHG Projections up to 2050 using as a base the inventory for the historical years, and taking into consideration Policies and Mitigation Actions (PaMs). This work will be continued as the assessment of applied measures and investigation of additional measures is an ongoing work for the governmental stakeholders and scientific support is vital.
- **Effectiveness of current air quality NAP:** As already stated, cost-benefit analysis of the proposed measures is a significant component of the national action plan on air quality, and these components will be further addressed with health impact assessment studies. Additionally, towards the goal of the Forum for Air quality Modelling (FAIRMODE) to assess the modelling skill in supporting and/or complementing the reported air quality status over Cyprus, CARE-C team will continue participating in community intercomparisons exercises aiming at multi-component aspects of emissions/pollution characterization.

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