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Enhancing Learning about Climate Change Issues among Secondary School Students with Citizen Science tools

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***Abstract*—Citizen science is a valuable tool to inculcate awareness among citizens about climate change issues. This is also the main goal of the I-CHANGE project. On these lines, Hasselt living lab as part of the I-CHANGE project developed a collaboration with a technical secondary school. Digital sensors such as Meteotrackers and smart citizen kits will be utilized under this collaboration where students and teachers will not only collect data, but will be using it in an innovative manner to integrate the findings obtained from its analysis to enhance students learning about climate change issues. This paper presents a structured methodological approach to achieve this goal.**

Keywords—Citizen science, I-CHANGE, Secondary school students, learning and education

I. Introduction

By including the general population in scientific procedures, basic or applied research concerns can be addressed. As long as data collection techniques don't necessitate specialised equipment or a highly skilled workforce, citizen science can be particularly useful for investigations requiring repeated data collection at numerous locations across a wide geographic area [1,2]. The widespread use of smartphones with internet access has made it simpler to collect data from many users using project-specific apps. In order to answer broad issues, citizen scientists can significantly increase the amount of data being gathered [1, 2]. Participating in citizen science has been demonstrated to provide broad cognitive benefits for individuals in addition to making a major contribution to scientific understanding. Studies have shown, for instance, improved knowledge of the scientific method, the development of a scientific mindset, the retention of subject matter knowledge and a realization on their own ability to do science [3].

The mitigation of climate change's primary causes (in the form of response to disaster risks) and the adaptation and resilience of people, socioeconomic and ecological systems have been the two basic axes on which climate change mitigation measures have been founded [4]. Studies carried out in various contexts have demonstrated that citizen engagement empowers individuals to better understand disaster and impacts from extreme or slow-onset climate events and act in response [5]. By encouraging community-based data gathering, citizen science can document regional observations on the impacts of climate change. It might be helpful for advancing statistical analysis of heterogeneous data and improving studies on the patterns of climate change, both of which would increase scientific understanding. It can help with the comprehension of regional and global patterns of climate change, provide concrete evidence of its effects, and aid in the calibration and improvement of services and instruments related to weather forecast, flood alert, among other things, assisting in the early warning of hazards that aid in assessing and managing impacts [6].

The involvement of students instead of the general population in citizen science activities may allow them achieving to achieve higher-level cognitive gains primarily due to the structured nature of the content and sequencing of scientific information and practices [7]. An effective strategy to help secondary school students conceptualise science and how it is done is to involve them in the quest of innovative research discoveries [8, 9]. Participating in research has also been demonstrated to be a good method for students to develop their communication and critical thinking abilities, as well as their creative and interpersonal skills. Students may retain some information and even find it interesting if a teacher lectures to classes about the importance of having clean water. However, would scientific comprehension and interest change if those same students were taken to a stream, creek, or lake on the school or community property and allowed to sample the water and take measurements in order to determine water quality? It is indeed proven to be true that knowledge obtained by practically experimenting is far more meaningful and have a long-lasting retention within the students [10]. Science educators are currently overburdened to meet the demands of students, and to this end citizen science projects fit very well to the teachers' requirements. Visionary educators should understand that citizen science's active, inquiry-based approach will help to simultaneously solve a number of issues. The likelihood that students will absorb the material, comprehend the nature of science, and start to contextually understand what it means to be a part of a larger environmental community is greatly increased [10].

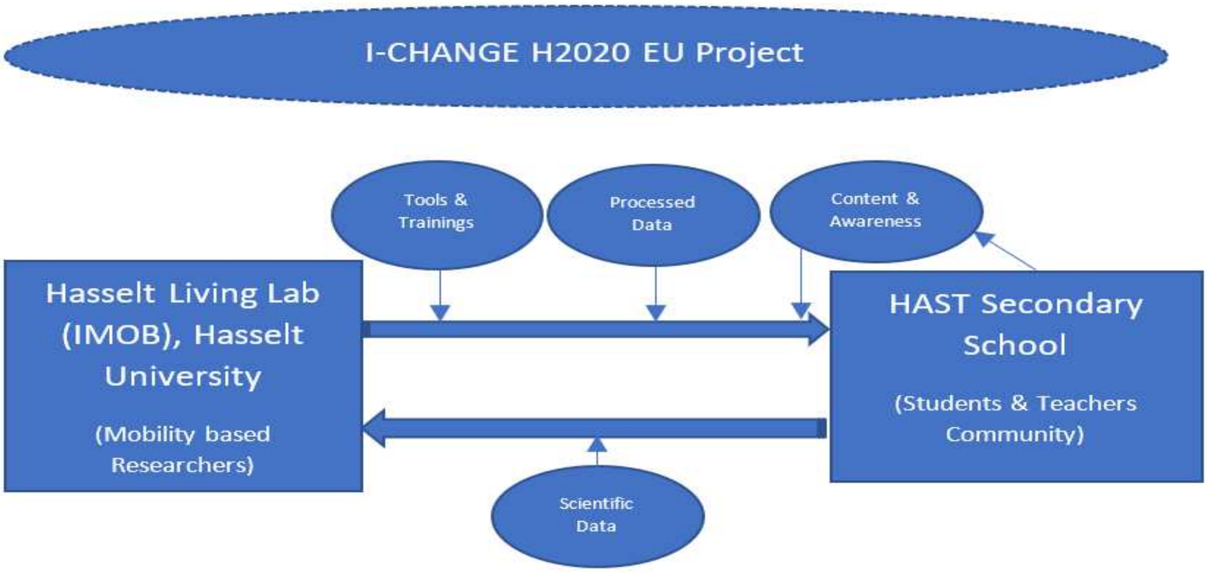

Fig 1. Collaboration Framework

Several websites (e.g. https://scistarter.org) provide support by providing an inventory of 1540 (August 2023) citizen science projects. Some of these are suitable for school children and teachers. The collection contains only a few projects focusing om mobility or transportation. In general, the majority of citizen science projects suitable for secondary schools focuses on ecology. In [11] the authors analyze 77 papers and provide a review that synthesizes the current body of evidence on the type of activities in school-based citizen science initiatives by K–12 students (children from 3 to 17 years old). Activity types (collecting, transcribing, categorizing and analyzing of data) as well as the level of participation (crowdsourcing distributed intelligence, participatory science and extreme citizen science) are considered to characterize and classify the projects. *Extreme citizen science* is defined as "*largely driven by the participants themselves*", in this case the K–12 learners, from project inception, scoping, experimental design, and interpretation of results" [12]. The authors emphasize the importance of engaging the students actively in citizen science projects beyond reducing them to "*citizen-sensors*." Mueller et al [13] triggered several responses including an elaborated discussion on the subject on the topic of '*citizen science at school*'. One of these responses as described in [14] lists pitfalls and difficulties. One of these is the lack of access to scientific literature by the public and hence by the children. The authors seem to have guided a classroom of students who in the end wrote a paper and submitted it to a journal. For our context this seems to be too difficult for the pupils. But the authors also mention the interesting idea and experience of maintaining a co-authored document about the classroom research in a wiki.

This paper presents a structured methodological approach through which teachers and students are involved in a citizen science project (i.e. I-CHANGE) to address a wide range of climate change related research questions which not only become a data collection exercise but at the same time provide a learning opportunity for students by directly associating the collected data within the educational content. This is achieved by establishing a working collaboration between a scientific institute (Transportation Research Institute, IMOB at Hasselt University) and a technical secondary school HAST. A technical school is a secondary school that prepares children for continued education towards a job as an operational technician (i.e. it does not prepare for university level studies). Our goal is to make pupils and teachers aware of the effect of mobility choices on the environment (climate change). We try to achieve this goal by involving them in a study that quantifies their observed mobility patterns. Analysis and interpretation of the results in the classroom context is expected to contribute to their ability to select travel modes based on critical reflection and not just based on habitude. The academic researchers support the pupils and teachers by processing the raw data and by supplying pre-processed data that can be used in the classroom. Phillips et al [15] state that students should be aware that they contribute to "*real science*" (i.e. contribute by collecting and analyzing data that enhance the current body of knowledge). Although this holds for our project, the main objective of the I-Change HAST project is to raise pupils' awareness by allowing them to apply the content of their courses to observations of their own behavior. Calabrese Barton [16] argued that parents and families should be involved in citizen science that by itself should not be bound to a school but to the local community. The authors mention the particular case of the transformation of a power plant in Lansing (Michigan) where the youth set up a citizen science program investigating and evaluating the effects on the local community and was able to affect the final decision. However, applying citizen science to achieve immediate local effects is possible only in particular cases. Many projects aim for a large part to raise the population awareness of environmental problems (e.g. https://curieuzeneuzen.be/het-onderzoek/ in Flanders, Belgium about "cities as heat islands"). In our case (Hasselt, Belgium), there have been severe floods nearby (at a distance of 50 km) in 2021. The weather becomes less predictable and sudden variations in wind speed and precipitation do occur (summer 2023). The pupils are aware of this but may not be aware of the effect of their own behavior on the observed phenomena. This is because the contribution of each individual is very small, the changes do occur over long periods and climate change may only be visible at a large distance from home. Furthermore,

Fig. 2. Smart citizen kit (Left) and Meteotracker (Right)

transportation is only one of the contributors to the climate problem.

The paper is structured as follows. The next section describes a framework under which the collaboration is formed between the two institutes along with the details on citizen science instruments. Section 3 presents a proposal on the research questions at secondary school level that are developed to inculcate a climate change knowledge. Section 4 discusses the ethical and legal protocols that will be followed within the collaboration. Section 5 concludes the paper.

II. Collaboration Framework

As mentioned earlier, a collaboration is established between the technical secondary school (HAST) and Hasselt living lab which is running under the Transportation Research Institute (IMOB) at Hasselt University. A working group is formed that contains researchers from Hasselt living lab and several directors who are managing and coordinating informatics and science related courses at 8^{th} grade (3^{rd} level of secondary education) and above in the technical secondary school. Fig. 1 depicts the main elements of the collaboration framework.

This entire collaboration is based on achieving the key goals of the I-CHANGE project which are required to be realized within the Hasselt living lab. The major goal of the I-CHANGE project is to raise climate change awareness among citizens by using citizen science approach. The project involves eight (08) living labs which are addressing different environmental and climate change issue in terms of awareness raising campaigns. Hasselt living lab under I-CHANGE project is working towards co-designing, implementing, and assessing novel strategies and interventions fostering behavioral change in relation to mobility-oriented lifestyles of citizens, focusing on switching to sustainable activity-travel behavior (not only on more use of active travel modes but also on the activity formations within and outside home that help reduce negative effects of travel, such as telework, e-shopping). More information about the I-CHANGE project can be obtained via the website: https://ichange-project.eu. Technology has become a central component of citizen science [17] as a tool for engagement [18], community building [19], and data collection [20]. The experiences gained from novel implementations of technology in citizen science are thus broadly applicable. For this purpose, the project utilizes a few sensing tools such as Meteotracker and Smart citizen kits (see Fig. 2).

Meteotracker is a mini weather station specifically designed to collect weather related data such as temperature, humidity, pressure etc. while on the move. These sensing devices can be easily installed on bicycles, cars and buses etc. Furthermore, this sensor works with a smartphone application which helps in geo-tagging weather data, real-time visualization and uploading data to the cloud. All uploaded data then is available on a public web-platform for visualization and further analysis for scientific community (More information can be obtained from https://meteotracker.com). The Smart Citizen Kit is aimed at providing a low-cost environmental sensor solution that non-user (i.e. average citizen) can easily deploy. The Smart Citizen Kit is an Open-Source platform that comprises 3 technological layers: a hardware device, a website and online API, and a mobile app. This sensor is able to collect data about weather conditions (temperature, pressure, humidity), noise pollution, light pollution and air quality (such as particulate matter PM_{10}, $PM_{2.5}$, PM_1 etc.)(more information can be obtained from https://projects.fablabs.io/+fablabbcn/smart-citizen-kit).
Under this collaboration both these sensors will be utilized, with a basic idea of collecting home to school trajectories while moving on the bicycles along with weather information Therefore, major emphasis will be given to Meteotrackers as students and teachers will be using this tool. Smart citizen kit will also be installed at various locations around the neighborhood of the school. However, because of the limited availably of Meteotrackers, a smartphone-based application will also be used to collect trajectory data (for example GPX tracker applications). The collected trajectory data will be stored in the database and after some simplified processing, the teachers and students can have access to this data. In addition to this, certain trainings will also be provided for the installation of sensors, for visualization of GPS traces using open-source geographical information system (such as Q-GIS software) and for solving a variety of questions with

basic analysis of the collected data (Section III provide more details on this aspects).

It is envisaged that this data collection will last for the whole academic year and then periodically teachers and student can work on the data to find some preliminary results. All this can be made part of the educational content to raise climate change awareness. Teachers can integrate such resources in their educational content to provide hands-on training on certain data processing, visualizing and analysis aspects (informatics and other science/STEM subjects). In addition to this, the trajectory and environment data collected from the engagement of students and teachers is valuable to answer a large variety of advanced research questions for mobility and environmental scientists. For example, fusing the weather and air quality data obtained from this engagement with other third-party sources (other project data) to analyze variation in weather and air quality with respect to space and time. Additionally, this can help to improve map matching algorithms based on the GPS based trajectories. Furthermore, this data can be helpful in examining route choices of individuals while travelling to different activities and by evaluating how weather and different seasons are affecting changes in travel patterns such as frequency of activities, their destinations and routes followed to reach the activity locations. In this way, this collaboration is a win-win scenario for all three entities the I-CHANGE project, HAST and Hasselt living lab.

III. Questions for Raising Climate Change Awareness: Secondary School Students

Hasselt living lab researchers prepared a proposal explaining the information the project aims to collect, the way HAST and UHasselt can cooperate and the final goal to raise climate change awareness for students. Hasselt living lab researchers also prepared an initial list of questions to be answered by the pupils and a list of exercises that pupils can apply in the classroom to the data they collected in the project. The list covers multiple courses (socio–economic, biology, informatics, electronics, mathematics, (descriptive) statistics, physics, chemistry, meteo, languages (reading, writing), data presentation). HAST teachers evaluate and adjust this list and decide which of the questions are assigned to a particular course in a particular year. Both HAST educators and students will collect data. The HAST educators will establish class groups of participants.

An attempt has been made to develop concrete questions which are applicable for secondary school students based on the collected data which not only demands these application of some simplified data processing and manipulation methods but also create an awareness on a few pressing climate change issues specially in relation to travel habits, weather and air quality conditions of the surroundings. These questions were developed based on the various subjects and contents that are listed in the syllabus guidelines of various courses taught in the technical secondary school. A few of these questions are given below.

- After the calculation of trip distance based on the trajectory data for past one week, calculate the amount of fuel consumed if a car is used to travel this distance and find out the travel cost in euros. Additionally, calculate how much CO_2 is emitted during such travel?
- Using the same question as above, but instead of using car as a mode of travel, it is now assumed that bus is used for such travel. Recalculate the amount of CO_2 emitted per person with certain assumption on number of people in the bus.

The above questions raise awareness about GHG emissions using different modes of travel. The students are using their own datasets to calculate such information which inculcate a self-realization about their travel habits and their impacts on climate change. Of course, this exercise needs to be done when material on GHG and their effects are being taught in the class, the topic is more relevant to Physics and Chemistry related subjects. Other relevant question related to the above are given below; they relate to the concept of physical energy consumption, and how it is beneficial for one's health.

- How much energy (kilo Joules, kJ) did a student use for those trips by bicycle? Factors are available that convert physical activity effort in terms of energy as used by smart watches/phones.
- How many meters did a student climb while doing such travel? and how much increase in potential energy (kJ) does this correspond to?

Some questions that uses weather data are for example formulated below and can be taught when weather science is explained:

- Take your data in the month of October and November and determine the maximum and minimum temperature experienced in each trip? Also find out the average temperature of each trip. Record this information and compare the variation between warm and cold days during this period. Also do the same exercise for humidity levels and find out what percentage of trips happened during a rainy period?
- Record every day whether you needed gloves during your cycling trips; which percentage of the trips does this happen? And relate such this with average temperature of the trip.

Based on air quality sensors, example of some questions is given below which are relevant to subjects like Chemistry, Biology and Health.

- Based on the smart citizen kit platform and other similar citizen science platforms, find out air quality sensors placed around your home and school neighborhoods and record the time series of particulate matter. How much concentration of these particulate matter is okay? Refer to EU and WHO guidelines.
- Are some students or teachers affected by a zone where the concentration of pollutants is high? Are there travel trajectories passing through such zones?
- Can we deduce from the time series graphs in the platforms that certain pollutant high concentration is because of traffic circulation nearby?

- Where does the particulate matter come from? What processes are causing it? What actions are needed if there is such problem in your community?

For courses like electronics and informatics, the questions based on the collected data can be formulated as:

- View the recorded GPS positions on a map in QGIS. Are they neatly in the middle of the road? Look up GPS accuracy data. Also check out what urban canyon effect means regarding GPS signals.
- What is the different type of sensors embedded in Meteotracker and smart citizen kit? How these sensors work? Are they calibrated? Are these sensors measurements compatible to each other?
- Where does the GPS data on the Meteotracker dashboard come from?
- Make a data flow diagram of the data ending up in the dashboard or in the resulting csv file. How do the measurement data end up in the computer?

In relation to mobility and geographical science related topics, the questions are formulated as:

- Taking a set of GPS traces, find some traces of people who use part of the same route?
- Using the Meteotracker dashboard data, are there greater height differences in trips outside the Flemish region?
- Choose a route/trip taken by someone; How much time that trip took? How much time would the same trip take by car (parking and walking from parking to destination included)? What is the distance?
- Are there car trips in the dataset? If so estimate the approximate time it took to cover the last five kilometers? by car, park and walk to the school gate. What is the average speed over that stretch? What is the average speed of a few bicycle trips with the same trip distance?
- Are there bus trips with destination HAST over a distance of five to ten kilometers in the data set? If so, then repeat calculations as mentioned above.
- In case we have multiple groups of participants, what is for each group in one given period (some week in November for example), the total length of the cycling trips, the average length of the cycling trips, and the average duration of the cycling trips?
- View each participant. Determine the number of days for a given period with (a) at least one bicycle trip or (b) without any bicycle trips.
- Are trips registered on weekends and days off? If so try to find out with QGIS, whether it concerns bicycle trips: look at the distance driven and the average speed and the roads on which the person moved, whether those trips are generally shorter or longer than trips to school etc.

In relation to Mathematics, Statistics and Informatics, some of the questions based on the collected data are formulated as:

- Use the Pythagoras theorem to calculate the distance between the two successive points?
- Take points P_0 (first point in the data) and P_{10} (10^{th} successor point in the data) and find the Euclidean distance between them? Also find distance between each pair of successive point in the data and cumulate the distance. Compare the two distances and articulate why two distances are not same?
- Find instantaneous speeds between the two successive points?
- Develop histograms of trip distances, average temperatures of the trip and average speeds.

The proposed questions as given above are very concrete and can be integrated easily within the context of various different types of subjects taught in technical secondary school. It will allow students to use their own data in the learning activities which help them understanding the local context and also aware them about different climate change issues together with the corresponding mitigation measures.

IV. ICT Tools and WorkFlow

A. Data Sources – Data Access

Only 15 MeteoTrackers are available. Hence, we have two kinds of participants: **SM+MT** (smartphone + MeteoTracker) and **SM+GPX** (smartphone equipped with GPX recorder app).

1) SM + MT

- The MT app on the smartphone controls the data collection. The user starts and stops the recording *session* for each trip.
- The MT acts as a meteo station and provides data via Bluetooth to the smartphone.
- The smartphone app collects collects meteo data and postion (GPS coordinates) periodically (every 6 seconds).
- At the end of the session, the smartphone app uploads the collected data to the central MeteoTracker server as private data (i.e. accessible only to the generator)
- Graphs and maps are generated in real time by the app so that the user can track the trip data.

2) SM+GPX

- A GPX recorder app is installed on the smartphone.
- The user needs to start/stop recording for each trip. As soon as the smartphone has an internet connection, the user needs to upload the recorded GPX file to the HAST MS-TEAMS environment (see below).

B. Smart Citizen Kits

The SCK records several quantities depending on the incorporated sensors (e.g. humidity, temperature, NOx, noise). Data can be downloaded by means of a REST JSON API. We will combine the temperature and humidity of the fixed SCK stations that are continually online with the meteo data provided by the moving MeteoTracker stations. These observations will serve to estimate humidity and temperature at the locations reported by the people who participate by means of a GPX tracker on their smartphone only (SM+GPX).

C. Public Data from Open Projects

Websites like https://maps.sensor.community/ provide measurement data for the region where the students and teachers collect data. Particular tasks for the students do apply to the air pollution observations found in the Sensor Community project.

D. MeteoTracker Server

This server is operated by the third party MeteoTracker, Cagliari, Italy. The dashboard considers the I-Change recordings as *private* (i.e. not accessible to other people). Data can be downloaded by means of JSON (requires access token).

E. HAST MS-TEAMS Environment

HAST uses the Microsoft TEAMS environment. Every teacher and student have an HAST laptop at her/his disposal. Everyone is identified by her/his HAST email address.

- The TEAMS has een set up to provide a secure environment for each user. Everyone has a private space.
- Students have access to their private space via their laptop and smartphone. They will sync the recorded position data as GPX files (JSON) to their private space.
- HAST keeps a translation table between the email address and a unique numeric identifier. UHasselt will receive data bound to the numeric identifier and does not know the associated email address.
- HAST will provide an IChange TEAMS account to be used by UHasselt to retrieve the pseudonymized data.
- Apart from QGIS (see below), teachers may decide to use csv files (raw data) containing recorded data in the classroom for use in spreadsheet calculations (HAST has an *ICT* curriculum along with *electronics*, *mechanics*, etc), ICT students are taught how to design user interfaces and may use their own data in that context. Each student has access to her/his private data in the TEAMS environment.

F. UHasselt Environment

The UHasselt ICT environment is google based. For the I-Change project a Linux server maintained by IMOB is used.'

1) Linux Server(s)

- The Linux server picks up data files (GPX traces) from the HAST TEAMS environment periodically (automated procedure) and stores them in a postgresql/postgis database.
- Stop detection is performed to split tracks into trips for the cases where the users forgot to turn off recording.
- The Linux server picks up recordings from the MeteoTracker central server by means of JSON and stores the recordings in the postgresql/postgis database.
- The Linux server performs speed and distance calculations as well as map-matching and mode detection (if required). Upon request of HAST educators or UHasselt master students aggregated results will be produced by the same server (details to be decided).

2) postgresql-postgis

HAST teachers and students will use QGIS (www.qgis.org) on their local laptop to show and analyze tracks (trips).

- Thereto they need access to the postgresql/postgis database on the UHasselt Linux server. This is provided by setting up an ssh connection to the Linux server using port-forwarding.
- Data for a particular user are saved in the postgresql database in a SCHEMA owned by that user. Access to the SCHEMAs will be organized by establishing GROUPs that reflect the requirements of the HAST educators.

V. Process Details

Since recorded data will be used to solve the (research) questions mentioned above in the classroom context, the HAST teachers will select classes for participation and establish groups. We aim to have at least one MeteoTracking person (SM_+MT) in each group. Participants (both students and teachers) will record their home/school trips. They can decide to record other trips too. Recording is not limited to bicyclists. Walk, bus, train and car users are expected to participate too. Some people may use several modes depending on meteo conditions or day-of-week. Such phenomena may complicate the analysis but make the study interesting.

The collected data will be used for academic research too. We are interested in the effect of *meteorological conditions* and *group formation* on daily mode choice: e.g. how do co-traveling groups disintegrate as a function of temperature and/or precipitation (rainfall, snow)?

VI. Ethical and Data Sharing Considerations

Within the I-CHANGE project, there are set protocols which are well documented for data sharing, data usages and taking prior consent from the participants of citizen science engagement activities. However, within this collaboration, a special consideration is required to be taken because of the two fundamental issues. 1) Involvement of secondary school students (which are considered minors), 2) Collection of position data from Meteotracker and GPX based smart phone applications which are personal data fall under GDPR.

In relation to the first issue, with in the collaboration a specialized consent form is being developed that will be signed by the parents/guardian of the student who is participating in the project. The legal basis for processing personal data will be *consent*. Only students who are 13 years old and above are recruited for this project within the secondary school, yet the GDPR specification indicating that students aged 13 or older to give consent themselves is not possible given that the project is not limited to 'digital services', therefore, requiring parental/guardian consent is necessary. Teachers of the class are the person responsible for the recruitment and they will obtain the necessary consent and will not reveal any identification data (e.g. name, e-mail) of the student to any other member of the project. The teachers are the ones who will hand over the sensing devices to the students.

Meteotracker devices are working in conjunction with an app on the users' smartphone; the data can be recorded in three different ways which needs to be chosen before starting the data collection session, usually prompted by the app. These modes are public, anonymous and private. When *public* mode is chosen, the data in the MeteoTracker server is accessible to all via the MeteoTracker dashboard. Furthermore, the dashboard also displays the user name too. Anyone in the world can visualize and access the data. When *anonymous* mode is chosen the data is still accessible to all, but the dashboard does not display the username of the person who is involved in collection of the data. *Private* mode does upload the data to the Metotracker server, but only the user owning the data can visualize and access it. This data is only available to the person who was involved in its collection. As stated earlier, secondary school students are involved and to protect their privacy in line with the GDPR requirements, the project opt for *private* mode of data collection. IMOB will provide a designated user credentials to the teacher for meteotracker usage and IMOB in no way aware of which student is using which credentials. This allows direct access to the data via Meteotracker server by the IMOB server. This can be seen via a blue lines of data flow from Fig.3.

The data from the GPX application will be stored in the OneDrive at HAST, and via the SSH tunnel these data will be stored in IMOB server (i.e. stored in a postgresql-postgis database). Teachers and students from HAST also have access to the processed data from the IMOB server (yellow arrows in Fig.3). IMOB will only provide aggregated data to I-CHANGE consortium (only if needed). Furthermore, based on the above a legal contract has been developed by Hasselt University and signed by HAST. Hasselt University and HAST are considered joint controllers of the personal data under the GDPR. Furthermore, an application is also under preparation to seek approval of the project settings for Hasselt University ethical commission.

VII. Conclusion

The paper presented a structured methodological approach followed to involve secondary school students in a citizen science project to inculcate awareness on climate change issues. The central part of the methodology is the development of a range of questions that students (with support of their teachers) will address by involving in data collection, its processing and then analyzing it in various ways to obtain information, which eventually raise their awareness on several issues related to climate change. Necessary preparations (such as data sharing issues, ethical consideration) are currently being addressed to kick-off this project by the start of the next academic year.

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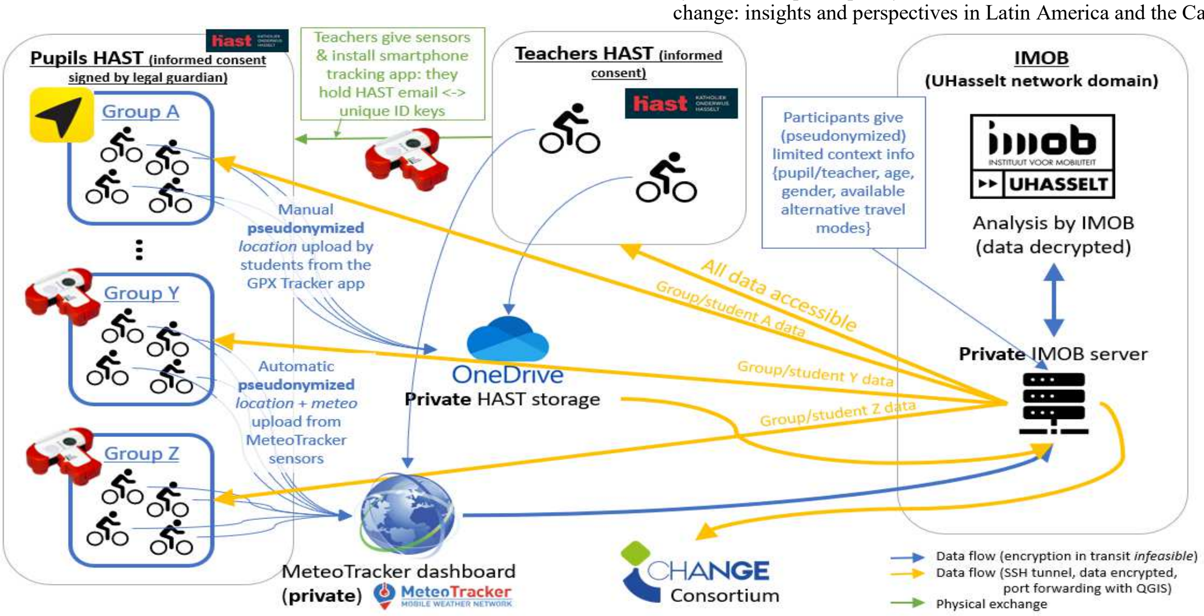

Fig.3 Data sharing protocols

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