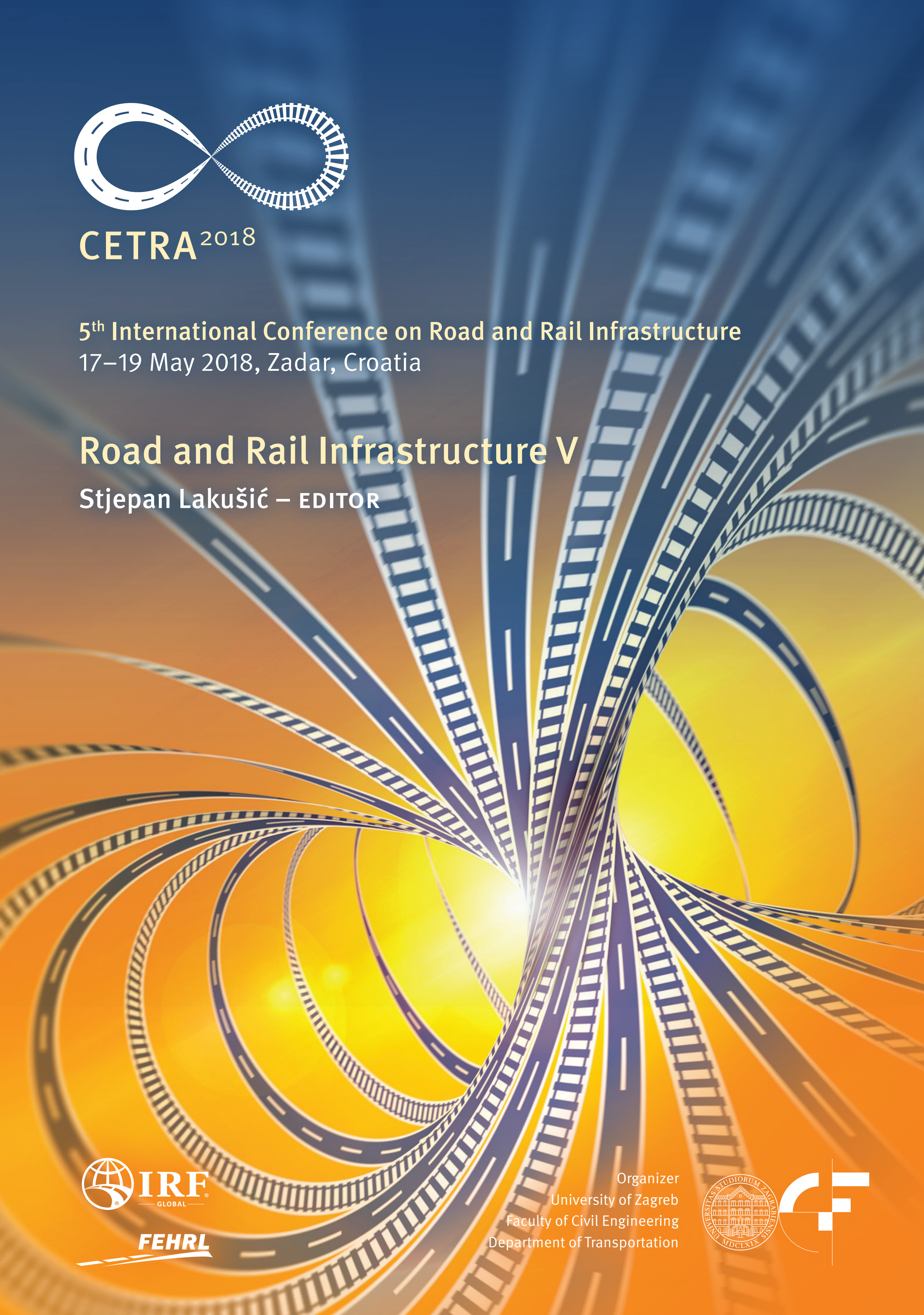

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5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

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OPTIMIZING ASPHALT PAVEMENTS FOR HEAVILY TRAFFICKED ROADS

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Abstract

The objective of the DURABROADS project, an EU 7th Framework Programme financed project (2013-2017) is the design, development and demonstration of cost-effective, eco-friendly and optimized long-life roads, more adapted to freight corridors and climate change by means of innovative designs and the use of greener materials improved by nanotechnology. Some its results are to be presented. It optimized asphalt pavement types and rehabilitation procedures for heavily trafficked European roads considering the synergistic effect of extreme climatic and mechanical loads. The European-wide questionnaire survey based quantification methodology included functional, economic, environmental and social-human aspects with weighing. After having used several statistical methods, weighted geometric means were applied to aggregate individual opinions into a consensual judgment. At the end, Stone Mastic Asphalt happened to be the most appropriate wearing course type. Based on the research conducted in DURABROADS project, it can be concluded that the addition of slags (up to 30%), RAP (up to 35%), WMA additive and bitumen improved with nanotechnology (actually by carbon black), either separately or combined, had no negative influence on the final properties (e.g. compactibility, stiffness, water sensitivity, resistance to permanent deformation and fatigue) of the asphalt mix. Guidelines were also issued to detail the procedures for the production and utilization for the "DURABROADS mixture" thus encouraging its implementation and harmonization within the EU road infrastructure sector and neighbour countries. The criteria to include the DURABROADS solutions into Green Public Procurement procedures were also defined, along with the recommendations of the next steps to be followed for the future standardization of DURABROADS mixture.

Keywords: green asphalt, warm mix asphalt, long-life pavement, climate change, nanotechnology, RAP, green public procurement

1 Introduction

A partly EU sponsored Collaborative project, DURABROADS (Cost-effective DURABle ROADS by green optimized construction and maintenance) was recently completed. It was led by Universidad de Cantabria (Spain) and participated ACCIONA Infraestructuras S.A. (Spain), Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. (Germany), KTI Közlekedéstudományi Intézet Non-Profit Kft. (Hungary), European Union Road Federation (Belgium), Fundacion Tecnalia Research & Innovation (Spain), Norwegian Graphite AS (Norway), BSRIA Limited (United Kingdom), Inzenierbuve SIA (Latvia) [1].
The objective of the DURABROADS project was the design, development and demonstration of cost-effective, eco-friendly and optimized long-life roads, more adapted to freight corridors and climate change by means of innovative designs and the use of greener materials improved by nanotechnology. The optimization of current construction, maintenance and rehabilitation

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procedures was also aimed at. Thus, existing constraints concerning these procedures and techniques to withstand challenges as the climate change impact and the high vehicle traffic loads of freight corridors would be identified, and evaluated in order to provide to highway managers with more affordable, safer and environment-friendly practices to manage the road asset. An analysis, characterization and selection of the most suitable carbon nanomaterials would be carried out to perform different polymer-modified and nanocarbon-modified binders. Several warm mix asphalts (WMA) incorporating these binders were to be designed and characterized. The maximum use of reclaimed asphalt pavement (RAP) and by-products in substitution of natural resources would be incorporated to these mixtures taking advantage of the expected improved properties of the new DURABROADS-modified bitumen types. Two DURABROADS pavement sections were planned to be implemented in a real case scenario. Furthermore, LCA and LCC studies were performed for the new asphalt materials developed, and results will be compared with conventional ones. Some of DURABROADS results will be subsequently presented [2].

2 Selection of optimal asphalt pavement type for TEN-T roads

The objective of Work Package (WP) 2 is to identify and to evaluate the existing constraints concerning currently used road materials and construction, maintenance and rehabilitation procedures and techniques to withstand current road challenges. Gaps were identified in road related materials and procedures. Based on the results of a comprehensive questionnaire initiated in WP2, typical materials and procedures used on highly-trafficked roads in Europe were analysed, and evaluated for optimizing them.

In the research works, 4 – Northern, Central, Western and Southern European – regions were differentiated. In some countries of every region, the typical bi-tumen and aggregate types, as well as their main standardised properties were identified.

The effects reducing road material durability were identified. It was stated that the rheological properties of bitumen change with time, this phenomenon is called ageing. The amount and rate of ageing depends on temperature, exposure to oxygen, chemical composition and structure of the bitumen, etc. There are four mechanisms of bitumen hardening: oxidation, loss or volatiles, physical hardening and exudative hardening. The ecological advantages of the production of warm mix asphalt, asphalt recycling and the use of industrial by-products were also scrutinized.

The following road rehabilitation techniques were included in the investigation: surface dressing, micro surfacing, cold asphalt mix, thin hot mix asphalt overlay, ultrathin friction course, resurfacing, cold-in-place recycling, hot-in-place re-cycling. The challenges and gaps in road-related procedures were identified, as well.

The long-term influences of climate change and of the implementation of freight corridors on European road network (TEN-T routes) were quantified. It is partly based on the results of a relevant targeted questionnaire survey. The actual pavement structural types on most heavily trafficked European routes were identified, and selected the ones, which are in line with the main project ambitions. The climate change elements critical to roads were identified reviewing the region-specific pavement deterioration forms they accelerate. Next, the traffic loads on European highway freight corridors were evaluated considering also their accelerated pavement deterioration forms. The synergistic effect of extreme climatic and mechanical loads was also studied assessing the influence of vehicle load to pavement surface at extreme low and high temperature, as well as on wet pavement surface. Considering extreme traffic and climatic load combinations on European heavily-trafficked (TEN-T) roads, a comprehensive quantification methodology was suggested for the characterisation of road-related materials, pavement design methods and rehabilitation procedures using the principles of lifetime engineering [3].

Since not every aspect can be expressed in monetary terms, their combination needs a preliminary step, scoring each aspect value after having ranked the relevant values for the competing course variants; the more favourable the value the higher the score. The combination of these scores should be done by weighing, and then adding them to calculate "Combined Sufficiency Value" (CSV) for the variant evaluated (weights could be based on expert elicitation including project partners during various reviewing phase):

$$CSV = (W_f \cdot S_f) + (W_{ec} \cdot S_{ec}) + (W_{en} \cdot S_{en}) + (W_s \cdot S_s) \quad (1)$$

Where:
CSV – Combined Sufficiency Value;
S_f – functional score;
w_f – functional weight;
S_{ec} – economic score;
w_{ec} – economic weight;
S_{en} – environmental score;
w_{en} – environmental weight;
S_s – social score;
W_s – social weight.

The "competition" of the wearing course variants (comparison of CSVs) could be performed for the four regions mentioned separately [4].

3 Investigation and development of more suitable carbon nanomaterials for the modification of binders

The objective of WP3 was the development and characterization of graphite-modified binder to be used in greener, cost-effective and more durable asphalt materials. The size, shape and quality of graphite nanoplatelets were investigated resulting from different synthesis methods and sources, in order to find out the most suitable oriented to the target application: high-performing additive for bitumen and polymeric matrices. After the literature review concerning the compatibility and processability of carbon nanomaterials with polymers, as well as those of carbon nanomaterials and bitumen, the following carbon nanomaterials were selected: exfoliated graphite nanoplatelets, graphite microflakes, expanded graphites, and graphite oxide made from expanded graphite received from expandable graphite. Graphene nanosheets were mixed into the bitumen. Two other materials were also studied: carbon black and nitrogen-doped graphene [5].
In addition to the characterization of carbon nanomaterials, the behaviour of the carbon nanomaterials at the processing temperatures (~150-160°C) and above was also investigated. Optical Microscopy, Single Electron Microscopy coupled with Energy Dispersive X-ray Spectroscopy, Differential Scanning Calorimetry, Thermogravimetric Analysis, X-ray Diffractometry were applied. The analyses confirmed the platelet/flake-like structure of the materials, their graphite (crystal) structure and their thermal stability in the temperature range of 150-160°C (where bitumen blends were prepared).
The "functionalization" of the carbon materials was not only limited to a chemical functionalization, but also included the processing of the graphite materials with polymer. Three approaches were considered: GNP-Polymer Compounding via Extrusion; Preparation of expanded graphite and synthesis of graphite-oxide (GO) from expanded graphite; In-situ activated graphene concentrates.
N-Graphene/Bitumen-Awas selected as the most promising modified bitumen extracted from the search and development of modified bitumen from nitrogen-doped graphene and/or from graphite oxide. The scenario as an alternative of graphite/graphene materials, gave the best results. It was thus chosen for the use in the subsequent WPs.

4 Development of graphite-modified WMA including the use of industrial by-products and RAP

Three types of asphalt mixtures, an asphalt concrete (AC), a porous asphalt (PA) and a very thin layer asphalt concrete (BBTM) were developed that incorporated the bitumen developed in WP3 (DB bitumen), maximized the use of reclaimed asphalt pavement (RAP) and industrial by-products. Besides, warm mix asphalt additives are also used to reduce the production temperature [6].
The objective was to provide an overview of the state-of-the art in the use of the green technologies for the asphalt industry; specifically the revision of five different technologies: RAP, WMA, RAP+WMA, slags and nanoparticle technology combinations. As a result of this investigation, the most promising materials and additives were selected for further study. It was concluded that the combination of nano-modified asphalt mixes with the rest of innovative approaches (WMA, RAP, steel slag aggregates) was beyond the state-of-the-art, and would result in a challenge for the DURABROADS project. The following three-stage work plan was followed for the analysis of the impact of the new bitumen and the effect of incorporating additives to reduce the production temperature:

- Three mixtures (AC, PA and BBTM) were designed with the alternative aggregates (EAF slag and RAP) and one commercial polymer-modified bitumen (PMB) to maximize the amount of EAF slag and RAP, and therefore to minimize the use of natural aggregates;
- Three new mixes (AC, PA and BBTM) with the same amount and type of alternative aggregates and PMB were produced at a lower temperature by incorporating a WMA additive;
- The nanomaterial-modified bitumen developed in WP3, DURABROADS (DB) bitumen, was used instead of the PMB but maintaining the previous WMA additive and alternative aggregates.

Since the pilot road was built in Spain, Spanish standards and regulations were considered for the design of the asphalt mixes. Characterization tests were carried out according to relevant European Standards. Different mechanical and dynamic tests were carried out to analyse the performance of each mixture:

- Tests required by the Spanish normative (PG-3): voids test (EN 12697-8), water sensibility (EN 12697-12), wheel tracking test (EN 12697-22) and particle loss in PA mixes (EN 12697-17);
- For a more accurate analysis of the mechanical performance of the asphalt mixes, the following dynamic tests were carried out: stiffness test (EN 12697-26), resistance to fatigue test (EN 12697-24) and workability test (EN 12697 – 31).

Main results and conclusions obtained from the characterization of the mixes were:

- An AC asphalt mix with 35 % of EAF slags and 30 % of RAP by volume was designed using 3.2 % of DURABROADS bitumen, which met all the requirements for conventional asphalt mixtures according to the Spanish specifications;
- The PA mix was manufactured with 77 % of EAF slags and 20 % of RAP by volume using 3.6 % of DURABROADS bitumen, meaning 97 % (v/v) recycled content;
- This mix was designed using 52 % of steel slags, 45 % of RAP and 3.6 % of DURABROADS bitumen, meaning 97 % (v/v) recycled content;
- All the mixes complied with Spanish specifications required for the highest traffic category and warmest climate areas;
- Values in stiffness are much higher than those for conventional mixes, being in the case of the AC mixture close to high modulus mixtures;
- The increase in stiffness affect negatively the fatigue resistance of the bituminous mixtures since the asphalt layer is less flexible. However, the result obtained is good.

Based on the research conducted, it can be concluded that the addition of slags, RAP, WMA additive and bitumen improved with nanotechnology, either separately or combined, accomplish the requirements of the Spanish standards for the highest trafficked roads. As the mixes with DB bitumen presented a lower fatigue resistance, the mixes would resist less cycles when subjected to a specific strain. However, their higher stiffness would make it difficult to reach that strain. Considering this, these mixes would be especially suitable for the wearing course since their higher stiffness would reduce the stress in the lower layers, increasing the fatigue resistance of the complete pavement and potentially increasing its durability.

5 Development of optimized road pavements more resilient to climate change and freight corridors

The main goal of WP5 was the development of asphalt pavements more resilient to climate change and freight corridors and the quantification of the environmental and economic impacts of the new developments and designs in relation to the new products. To carry out the optimized design of pavements, the American FlexPave software [7] was selected as part of the EU/US collaboration. In order to predict asphalt performance, the tool includes models that can represent fatigue damage growth and permanent deformation. The simplified viscoelastic Continuum Damage (S-VECD) model [8] is a mechanistic approach that has been applied effectively to predict the performance of asphalt concrete mixtures during pre-localization stages under different modes of loading. The rutting performance is evaluated in this tool using a permanent deformation model called shift model. Several simulations and analyses were performed to cover different materials, pavement structures, as well as the climate and traffic different in Europe from those in the USA, including the potential increase in temperature due to the climate change and the traffic evolution in each region. To do so, information from 19 European countries was collected on the daily standard axle load repetition number of the most heavily trafficked TEN-T section of each country, the annual heavy traffic progression (growth) rate forecasted for the TEN-T road section and the period for this annual growth rate. The temperature profile of the asphalt pavements was also needed for the analysis; therefore a new database was created for representative cities within the Central, Northern, Southern and Western European regions using temperature, wind and solar radiation (hourly data). Two Climate Change scenarios on the concentration of equivalent CO_2 were considered for the projection of temperature, wind speed and solar radiation.
Forecasted variations in climate variables are being collected from Regional Climate Models (RCMs), which have finer resolutions (10-50 km) than General Circulation Models (GCMs), and can incorporate relevant regional scale processes such as orographic lifting of air masses into their simulations. As in previous sub-tasks, this operation is being developed according to representative areas of the four typical European regions identified in the WP2 of the DURABROADS project: Central, Northern, Southern and Western Europe.
Twelve road pavement structures were simulated to analyse the effect of asphalt layer properties on the road pavement performance during its lifetime, considering the temperature profile of Frankfurt. According to the results, road asphalt pavement incorporating AC DB asphalt mixes in the surface course presented better mechanical performance in terms of fatigue and rutting comparing to road pavements that incorporate the control mixes. When comparing the three different DB asphalt mixes, road pavements incorporating DB-PA asphalt mixes had higher plastic deformation.
New simulations were carried out to analyse the expected increase in the pavement temperature profile due to the climate change in each EU region. Results showed a shortening of between 1 % and 25 % and between 33 % and 51 % in the fatigue and rutting resistance, respectively depending on the city analysed (Budapest, Riga or Frankfurt). In Madrid, the increase in temperatures does not practically change the fatigue damage, whereas the rutting increases significantly. The simulated road structure was found to be not suitable for the

region of Madrid, nor for Riga. In the first case, the high temperatures and heavy traffic of the TEN-T section considered required the use of a base and subgrade layers with higher bearing capacity. Therefore, new simulations were carried out using higher quality base and subgrade layers and analysing the effect of the type and thickness of the asphalt layers on the road performance. In the second case, the simulated road structure resulted to be oversized for the climate and the amount of heavy traffic in Riga.
An environmental and economic feasibility study of the materials developed in the project, DB (DURABROADS) bitumen and DB asphalt mixes, has been carried out through a life cycle assessment and life cycle costing analysis. In the analysis, three pavement mixtures (AC, BBTM, and PA) were considered. The DB Bitumen was designed to be used with all three cases, following which the overall mixtures were also modified with different additives such as Evotherm, carbon black and SBS (Styrene Butadiene Styrene); and steel slag, basalt as aggregates. This analysis was carried out for six cases where the base case was the asphalt concrete road named AC Base. The other five pavement alternatives namely AC Alt, BBTM Base, BBTM Alt, PA Base and PA Alt were compared against the AC Base case to select the one that has the lowest environmental impacts and maximizes net savings. The LCC Model was calculated as the net present value over a 50-year period using a discount rate of 6 % per year. The 50-year period has been selected to match the period used for the environmental impact assessment done in the LCA while the 6 % discount rate was chosen as it is a typical value used for a private sector construction project undertaken by a trusted investor. The total life cycle costs include the construction, maintenance and transportation costs. When analysing only the production of 1 kg of bitumen, a higher environmental impact of the DB bitumen is found due to the Carbon Black material used. However, when analysing the overall road system, AC Base has the highest environmental impact while the environmental damage caused by BBTM Alt is the lowest for the life cycle environmental assessment of the total road system.

6 Concluding remarks

The DB asphalt mixtures developed in DURABROADS project contribute to the reduction of the environmental impact of road pavements by the reuse of waste and the recycling of industrial by-products, by warm mix asphalt technique, and by increasing durability and resilience of road pavements.
The LCC assessment carried out has proven the cost-efficiency of the technology when compared with traditional materials by influencing the following costs: rehabilitation costs, costs associated with the purchase of natural aggregates, costs associated to waste and by-products landfilling. The multi-criteria methodology developed may be applied to a wide range of decision-making situations within the road pavement sector. This kind of methodology will help road authorities to select the alternatives according to economic, environmental and social criteria.
The guideline for introducing DURABROADS environmental concepts within GPP Green Public Procurement) processes is aimed to support the decision of the public bodies in adopting the technologies proposed in the project.
The use of DURABROADS solutions would contribute to achieve the European environmental objectives. Hence, the project meets the premises established by Europe 2020 strategy in relation to sustainable growth. It contributes to achieve the Europe 2020 target of reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020.

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