12th sdewes Conference Dubrovnik 2017

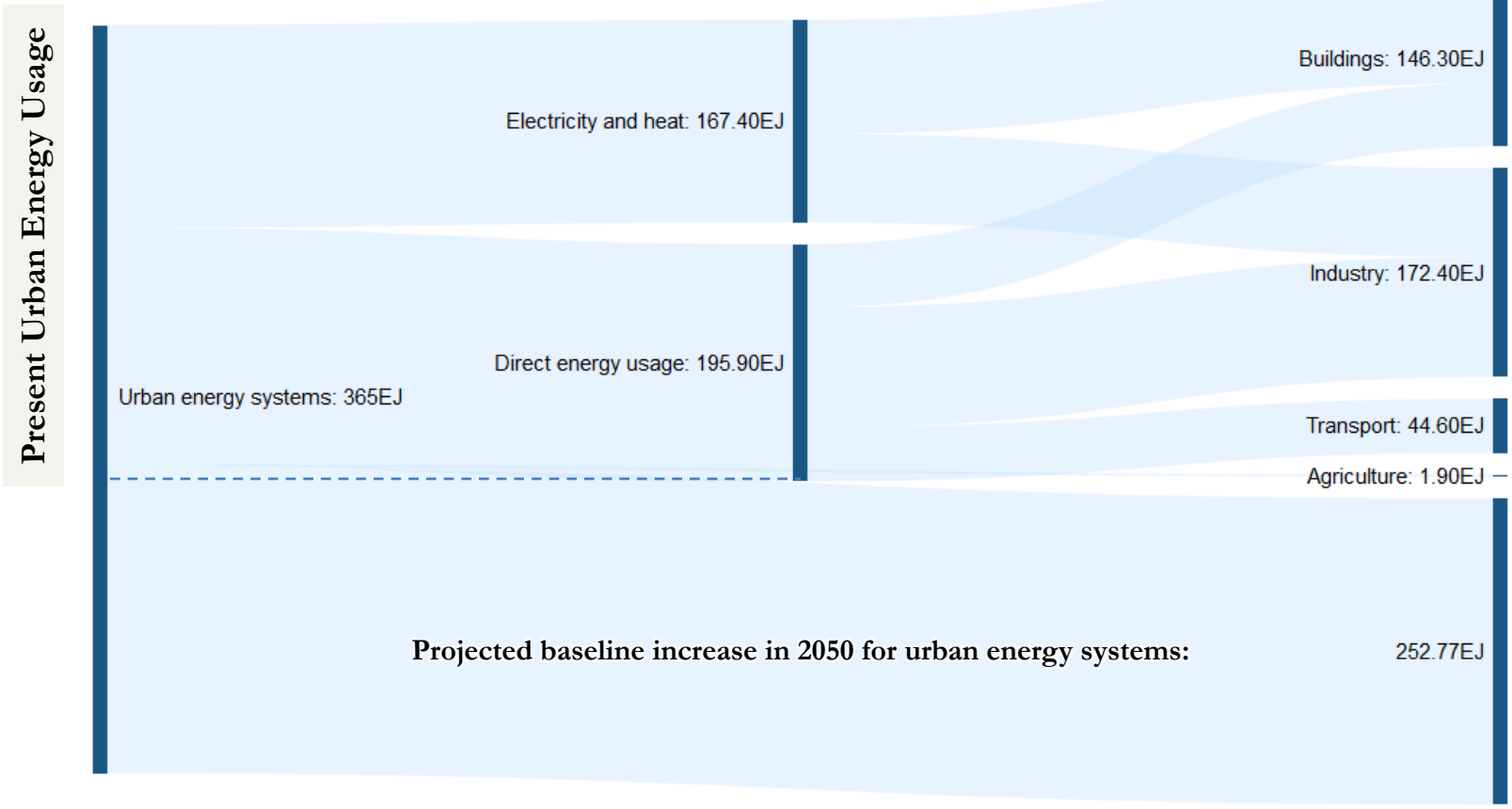
12TH CONFERENCE ON SUSTAINABLE DEVELOPMENT OF ENERGY, WATER AND ENVIRONMENT SYSTEMS

October 4-8, 2017, Dubrovnik

Benchmarking the Sustainability of Urban Energy, Water and Environment Systems with the SDEWES City Index and Envisioning Scenarios for the Future

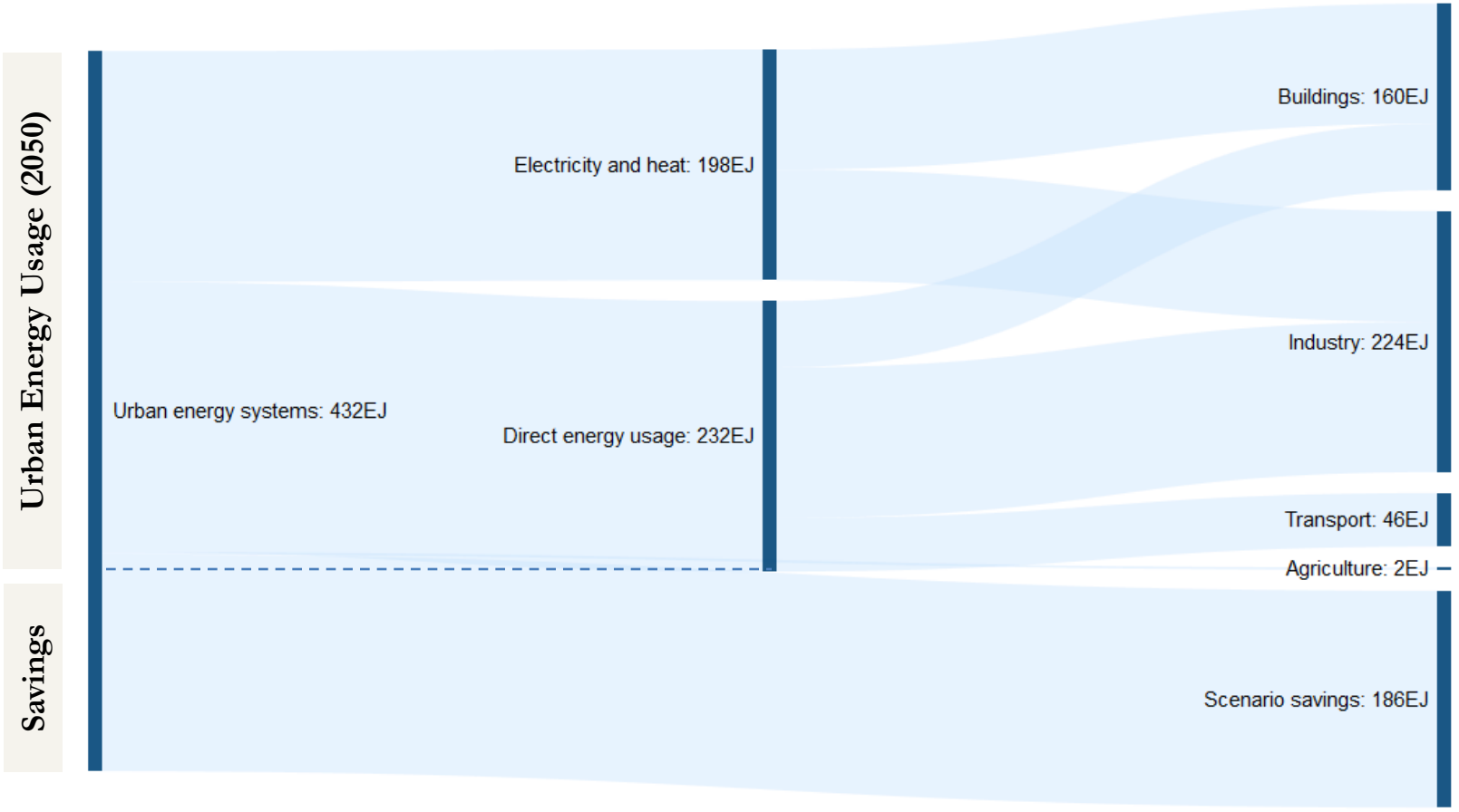
Şiir KILKIŞ
SDEWES International Scientific Committee Member
TÜBİTAK Senior Researcher and Associate Professor

Urban Energy Systems – Present Energy Usage



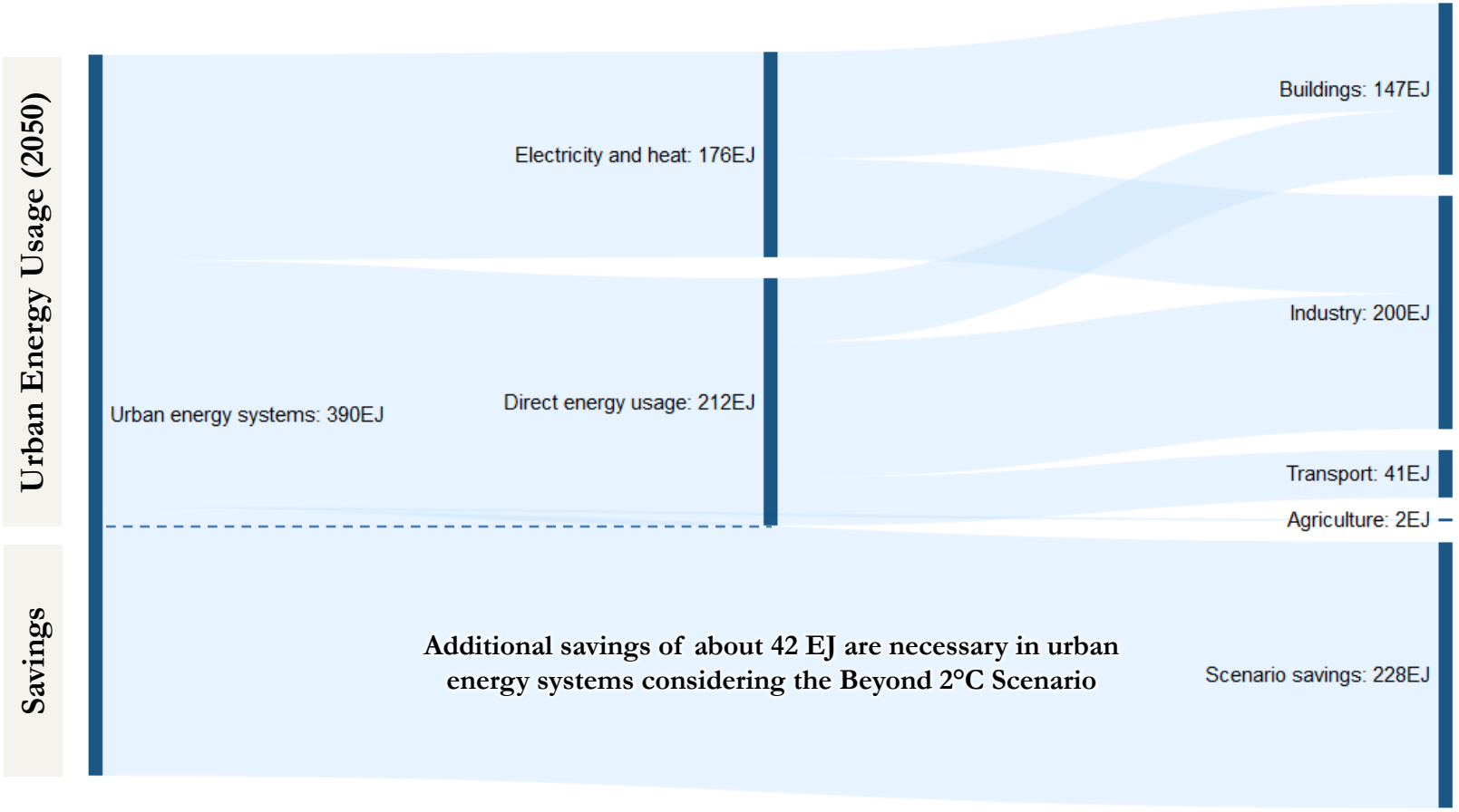
Drawn based on data from: IEA Energy Technology Perspectives 2016 - Towards Sustainable Urban Energy Systems

Urban Energy Systems – 2 Degree Scenario 2050



Drawn based on data from: IEA Energy Technology Perspectives 2016 - Towards Sustainable Urban Energy Systems

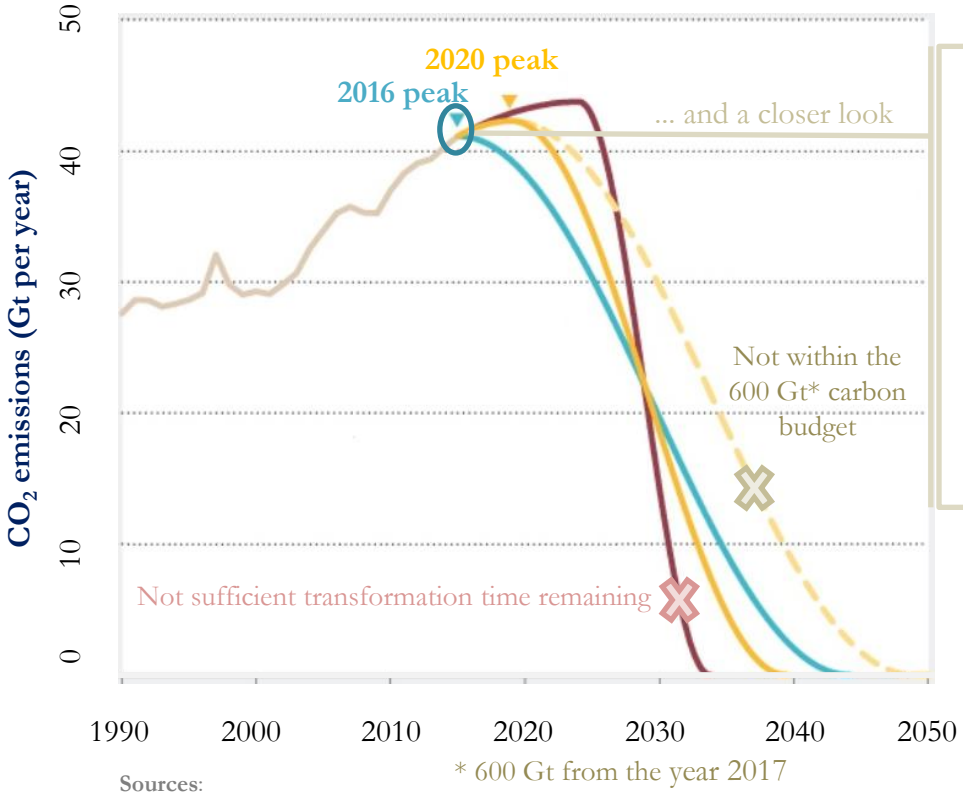
Urban Energy Systems – 1.5 Degree Scenario 2050

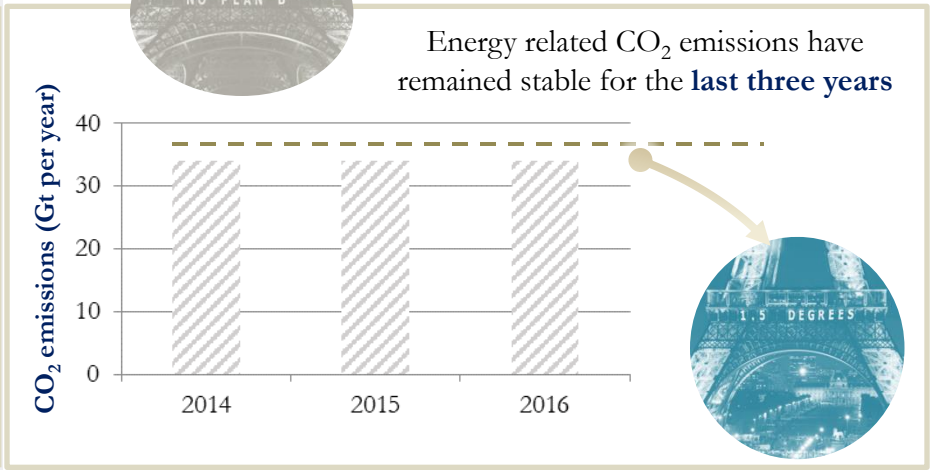


Drawn based on extrapolation of data from: IEA Energy Technology Perspectives 2017 - Catalysing Energy Technology Transformations

The Role of Cities in "Bending the Curve by 2020"

Cities have a crucial role in bending the curve by 2020 with a rapid decarbonization thereafter



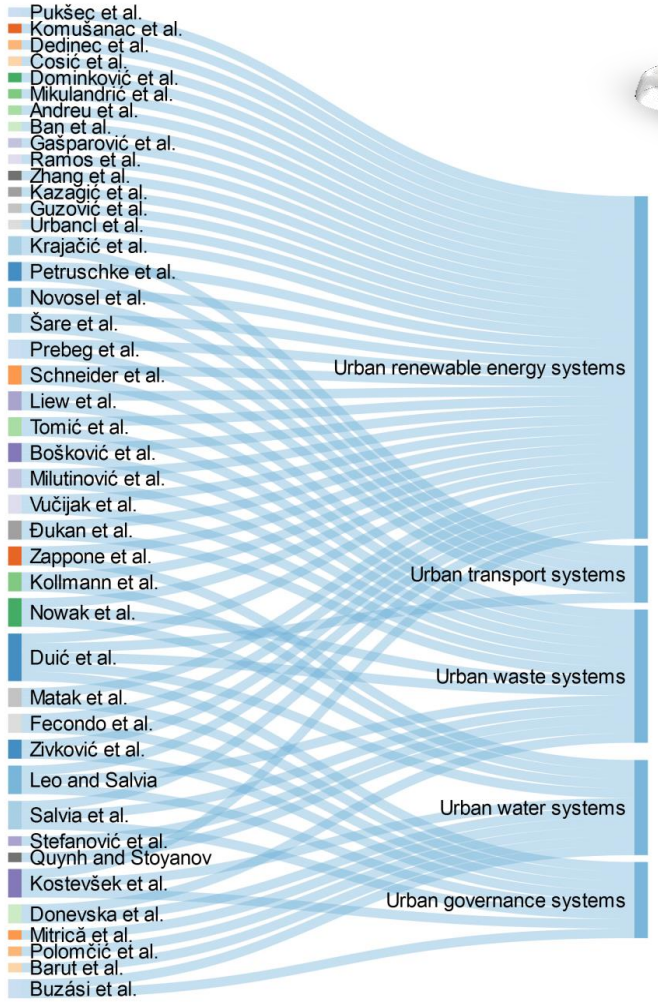


Sources:

- Stefan Rahmstorf/Global Carbon Project <http://go.nature.com/2RCPCRU>
- IEA Energy Technology Perspectives 2017 - Catalysing Energy Technology Transformations
- C40 Cities (2017), Deadline 2020: How Cities Will Get the Job Done

Exemplary Research in Support of Urban Systems

Examples from SDEWES researchers for South East European cities



- Integration of local energy and resource flows
- **100% renewable energy systems** (solar, wind, biomass, geothermal)
- District heating systems
- Smart energy storage
- Energy demand reduction
- Utilization of low potential and waste heat

- Electric vehicles, demand control charging, vehicle-to-grid schemes

- **Urban circular economy**
- Municipal solid waste management
- Waste to energy, environmental impacts of landfills

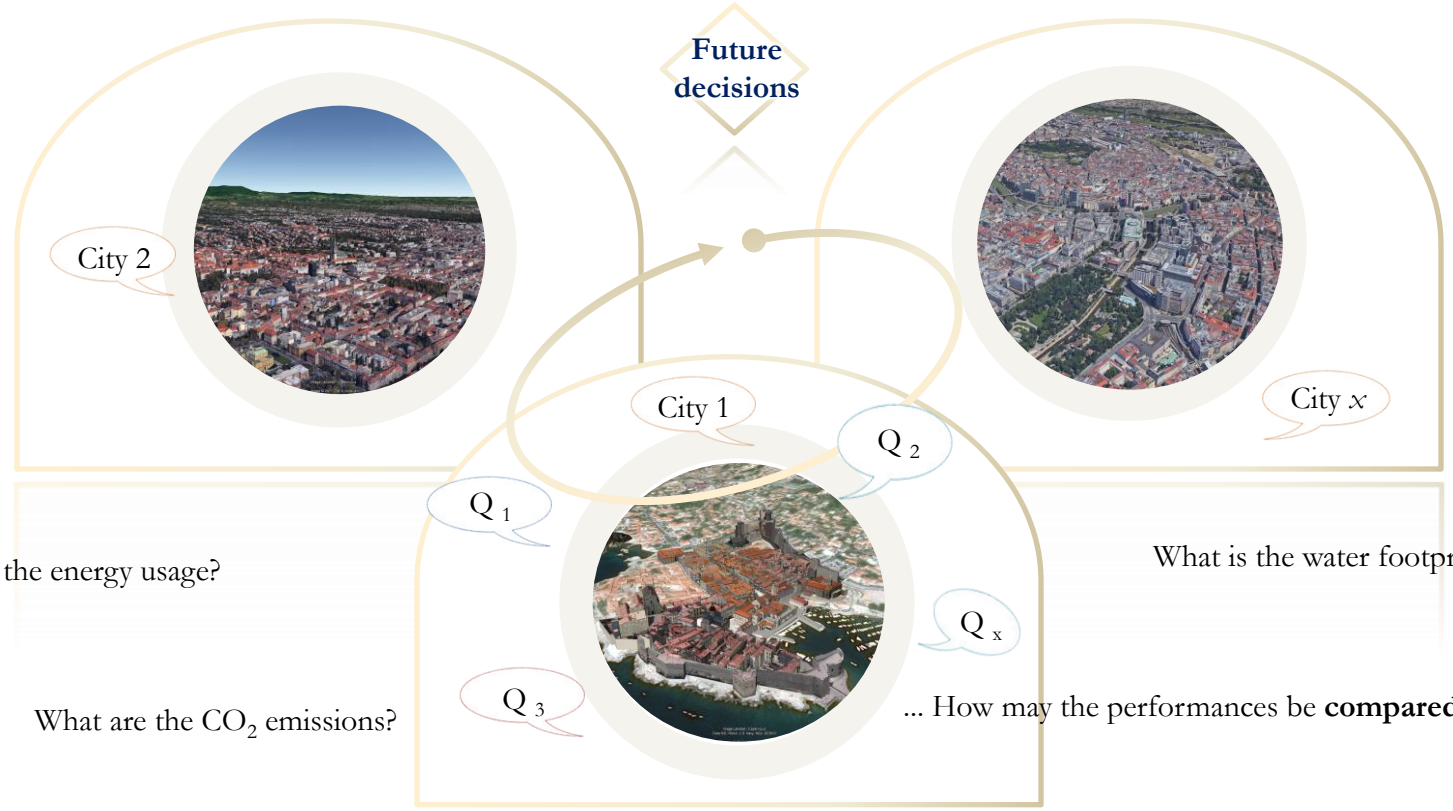
- Groundwater sources, urbanization impacts on watersheds
- Water balance, energy recovery from wastewater

- Environmental governance and joint SEAP
- Local energy, climate, and waste strategies

Benchmarking for the "Science of Cities"

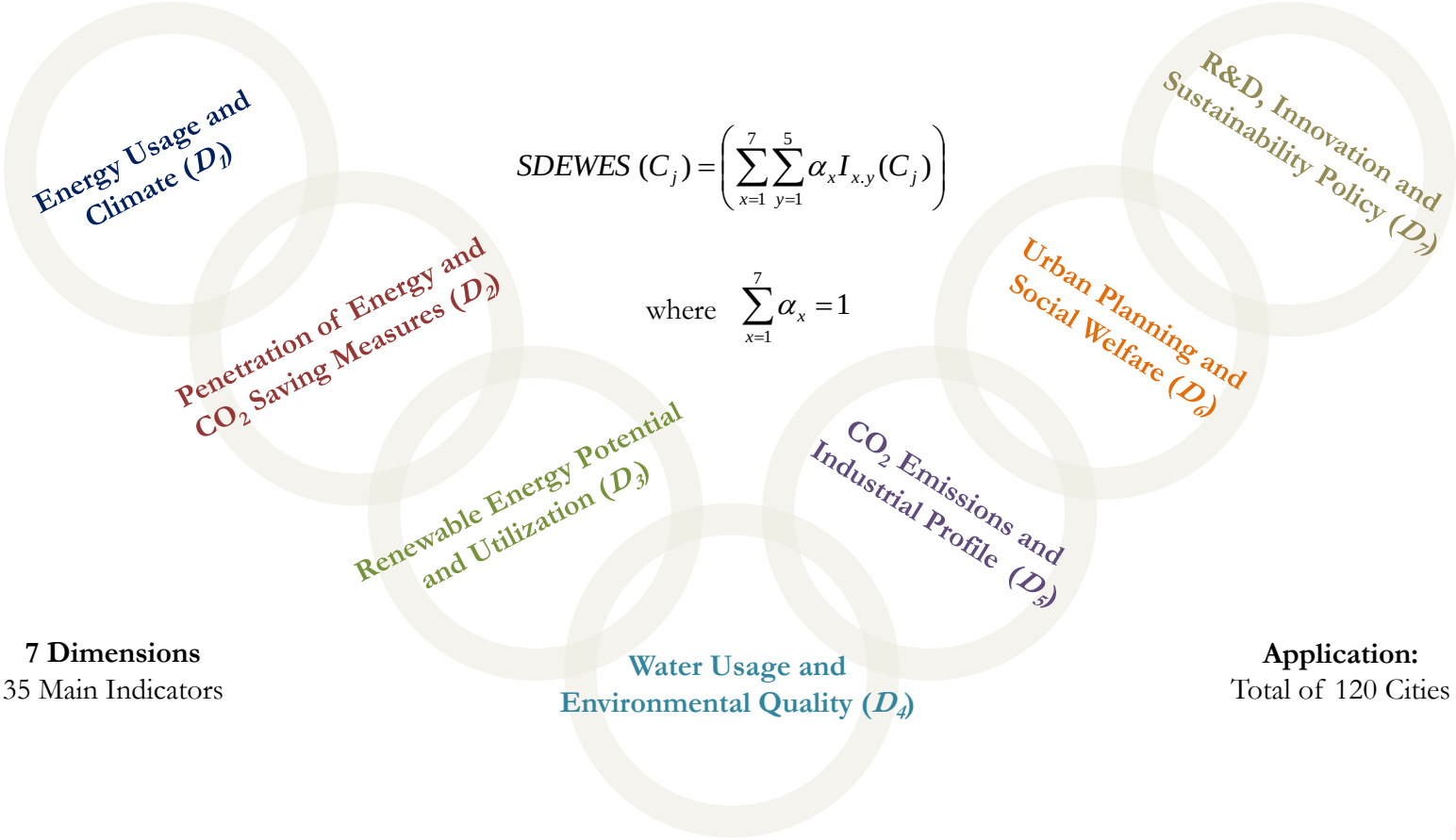
There is a need to advance methods for benchmarking as a means of supporting the "Science of Cities"

Composite indicators provide an opportunity to compare multiple dimensions



The SDEWES Index: Dimensions Overview

The Sustainable Development of Energy, Water and Environment Systems (SDEWES) City Index



$$SDEWES\ (C_j) = \left(\sum_{x=1}^{7} \sum_{y=1}^{5} \alpha_x I_{x.y}(C_j) \right)$$

where $\sum_{x=1}^{7} \alpha_x = 1$

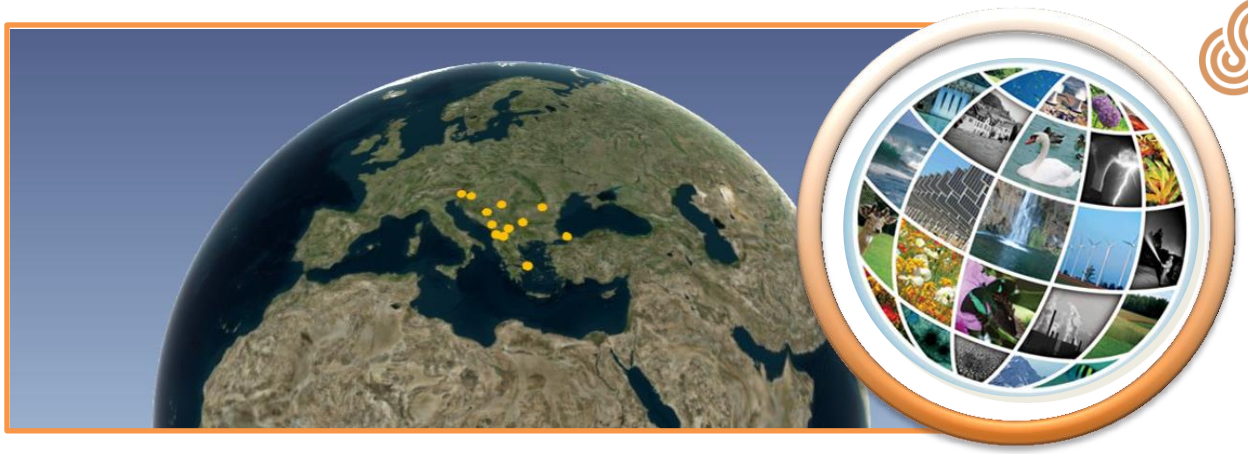
7 Dimensions
35 Main Indicators

Application:
Total of 120 Cities

The SDEWES Index: Application Overview

Selection Criteria

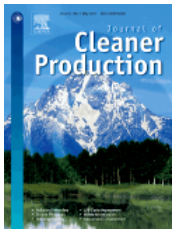
- Capital and/or largest city of countries in South East Europe (SEE)

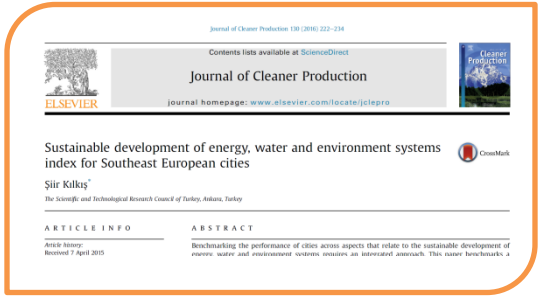


1st SEE SDEWES Conference Ohrid

Cities

- Athens
- Belgrade
- Bucharest*
- Istanbul**
- Ljubljana
- Ohrid
- Podgorica
- Sarajevo
- Skopje
- Sofia
- Tirana
- Zagreb




Journal of Cleaner Production 130 (2016) 222–234

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Sustainable development of energy, water and environment systems index for Southeast European cities

Şiir Kılkış*

The Scientific and Technological Research Council of Turkey, Ankara, Turkey

ARTICLE INFO

ABSTRACT

* District 1 with SEAP
** 12 districts on the Thrace side

The SDEWES Index: Application Overview

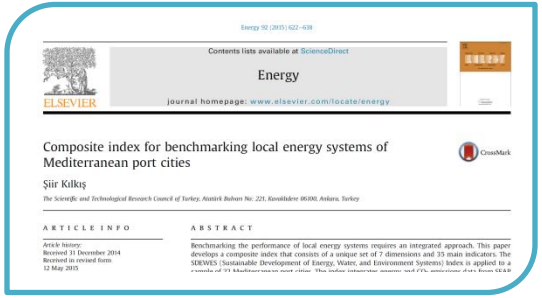
Selection Criteria

- City with a port on the Mediterranean Sea basin

9th SDEWES Conference Mediterranean

Cities

- Antalya
- Barcelona
- Bari
- Bornova
- Dubrovnik
- Genoa
- Heraklion
- Istanbul
- Kalamariá
- Karşıyaka
- Málaga
- Naples
- Nice
- Patras
- Pula
- Rijeka
- Seferihisar
- Thessaloniki
- Valencia
- Venice
- Volos
- Zadar



Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Composite index for benchmarking local energy systems of Mediterranean port cities

Şiir Kılkış

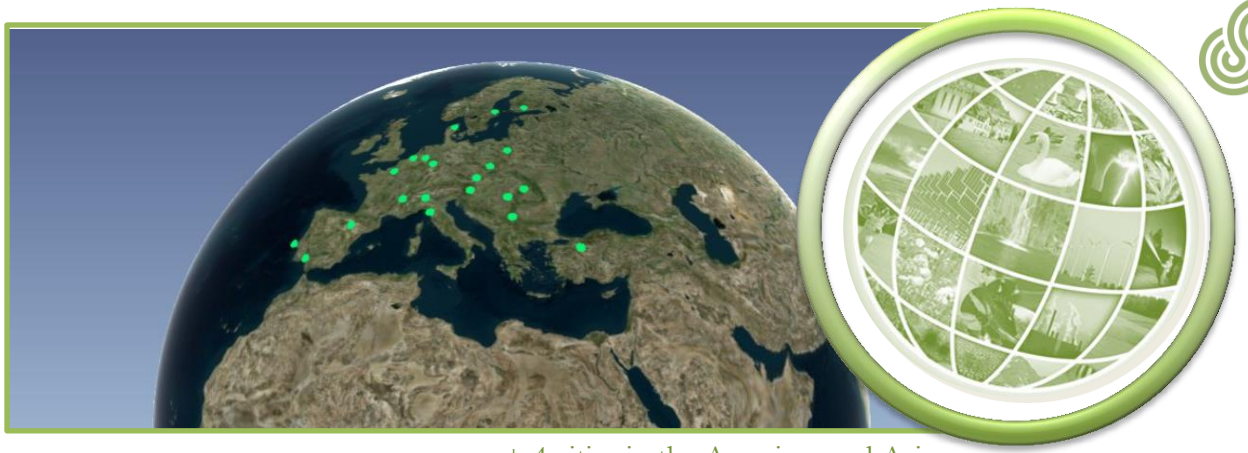
ARTICLE INFO

ABSTRACT

The SDEWES Index: Application Overview

Selection Criteria

- Cities with the most authors in the 9th SDEWES Book of Abstracts *

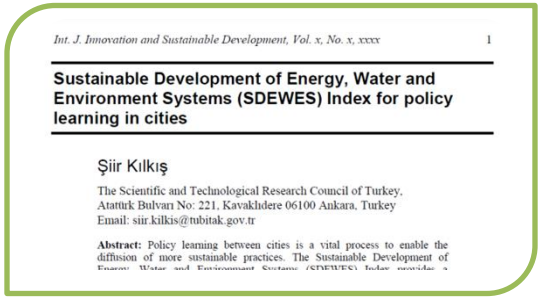


+ 4 cities in the Americas and Asia

10th SDEWES Conference Dubrovnik

Cities

- Århus
- Bogotá
- Cluj-Napoca
- Cologne
- Eskişehir Tepebaşı
- Espoo
- Frankfurt
- Grenoble
- Incheon
- Leuven
- Lisbon
- Maribor
- Milan
- Nagoya
- Niš
- Ostrava
- Paris
- Pisa
- Sevilla
- Stockholm
- Timişoara
- Vienna
- Warsaw
- Washington D.C.
- Zaragoza



Int. J. Innovation and Sustainable Development, Vol. x, No. x, xxxx 1

Sustainable Development of Energy, Water and Environment Systems (SDEWES) Index for policy learning in cities

Şiir Kılkış

The Scientific and Technological Research Council of Turkey,
Atatürk Bulvarı No: 221, Kavaklıdere 06100 Ankara, Turkey
Email: siir.kilkis@tubitak.gov.tr

Abstract: Policy learning between cities is a vital process to enable the diffusion of more sustainable practices. The Sustainable Development of

* Representative cities based on data availability also included

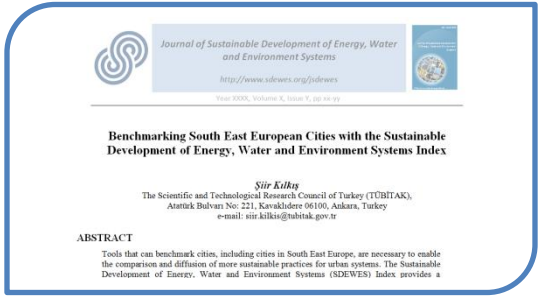
The SDEWES Index: Application Overview

Selection Criteria

- Cities in the SEE region (second sample)

Cities

- Bijeljina
- Brașov
- Bratislava
- Budapest
- Burgas
- Bursa Nilüfer
- Celje
- Izola
- Klagenfurt
- Kranj
- Nitra
- Osijek
- Pécs
- Rome
- Turin
- Varna
- Velenje
- Zenica



The SDEWES Index: Application Overview

Selection Criteria

- Multiple criteria to increase diversity

+ 4 cities in Latin America and Asia

Cities

- Amsterdam
- Antwerp
- Bangalore
- Batna
- Beijing
- Berlin
- Bilbao
- Braga
- Bregenz
- Bydgoszcz
- Copenhagen
- Florence
- Gothenburg
- Helsinki
- Karlovac
- London
- Lviv
- Lyon
- Madrid
- Porto
- Rio de Janeiro
- Salé
- São Paulo
- Tianjin
- Vila Nova de Gaia
- Vilnius

Criteria Components

- Most number of participating authors (↑)
- Total number of cities in the country with SEAP (↑)
- Inclusion of cities from the country in previous samples (↓)

The SDEWES Index: Application Overview

Selection Criteria

- Multiple criteria to increase diversity

Cities

- Aalborg
- Birmingham
- Bologna
- Cape Town
- Christchurch
- Constanța
- Dublin
- Funchal
- Gdynia
- Glasgow
- Hamburg
- Johannesburg
- Murcia
- Reykjavík
- Riga
- Sfax
- Sydney
- Tallinn

+ 4 cities in Africa and Pacific

Additional Criteria

- Monitoring Report or equivalent data submitted within the last 2 years

The SDEWES Index: Application Overview

In total, 50 cities from previous samples published updated energy and CO_2 emissions monitoring data

Covenant of Mayors for Climate and Energy (CoM), local plans, statistical yearbooks and databases

Monitoring reports submitted in 2017

Source: http://www.covenantofmayors.eu/actions/sustainable-energy-action-plans_en.html

Emission Reductions from Baseline Years

Measures

- Improved efficiency
- More efficient networks
- Increased share of renewable sources
- Shift towards public transportation and electric mobility

Source: Kona. A. et al. (2016) Covenant of Mayors: GHG Achievements and Projections

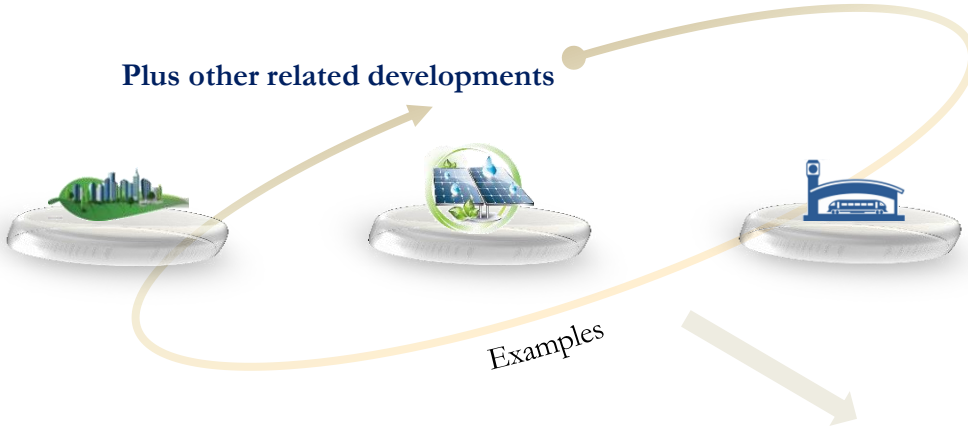
Supporting Questionaire

Energy and sustainability managers of cities

- Most recent energy, CO_2 emissions, and sustainability report for inclusion in this year's SDEWES Index

The SDEWES Index: Application Overview

Plus other related developments

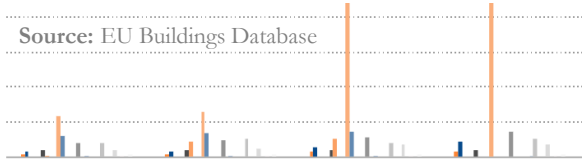


Climate mitigation actions

Demonstrations in pilot districts

Source: EU SCIS

Source: EU Buildings Database

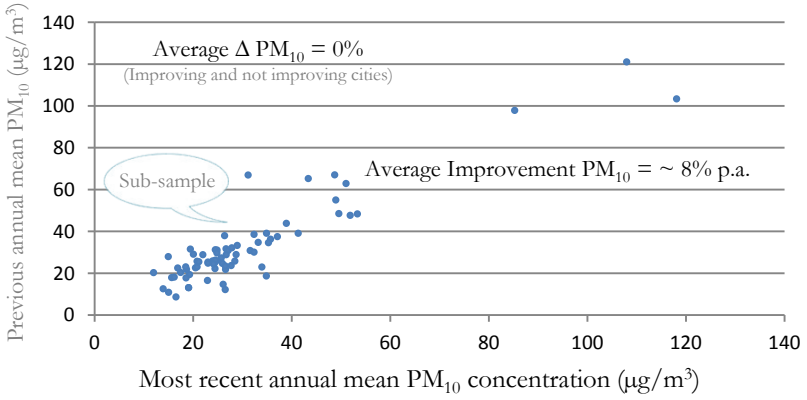


Share of Net-Zero Energy Buildings

Air quality levels

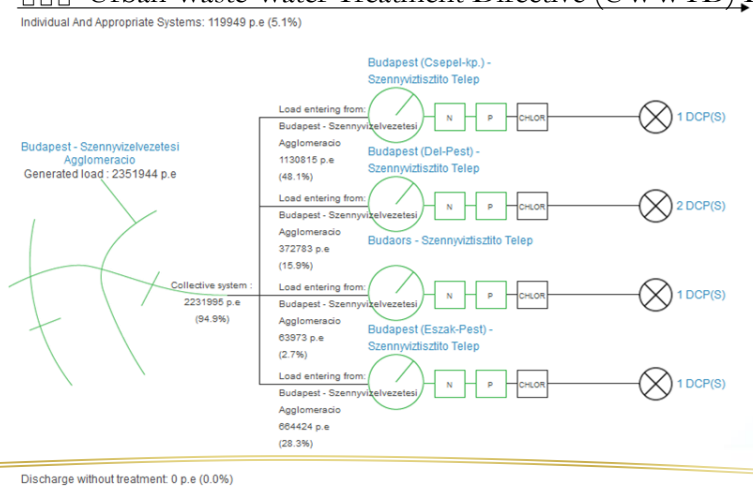
World Health Organization

Global Urban Ambient Air Pollution Database



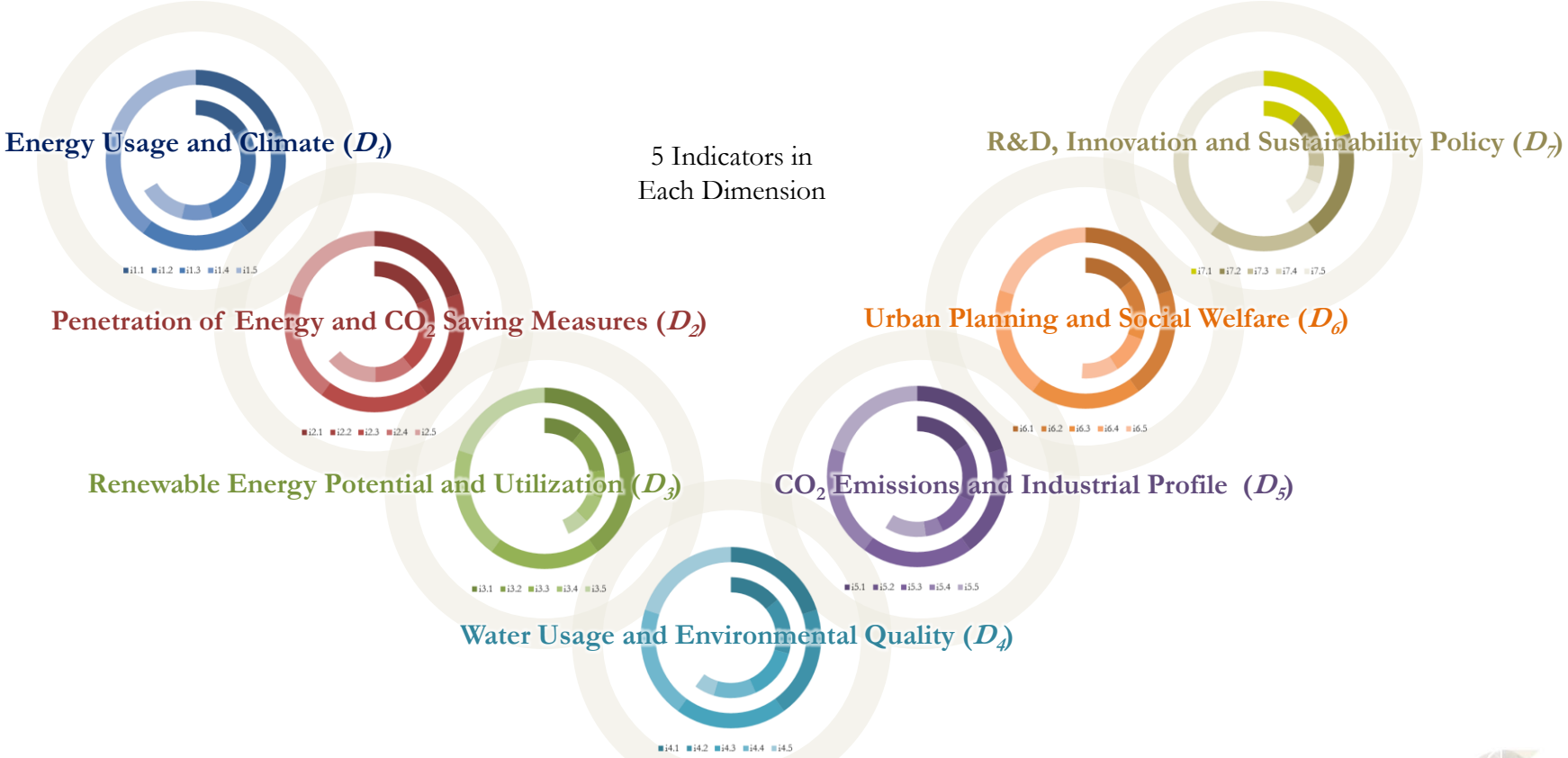
Water, wastewater and waste related aspects

Urban Waste Water Treatment Directive (UWWTD) Database



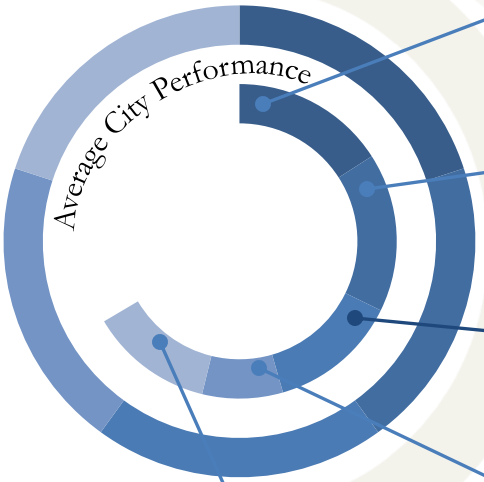
The SDEWES Index: Application Overview

The Sustainable Development of Energy, Water and Environment Systems (SDEWES) City Index



SDEWES Index – Dimension 1

Energy Usage and Climate (D_1)



Indicators:

$i_{1.1}$ Energy usage of buildings (MWh) [a]

$i_{1.2}$ Energy usage of transport (MWh) [a]

$i_{1.3}$ Energy usage per capita (MWh/capita) [a]

$i_{1.4}$ Total degree days (Days °C) [b]
Weighted by average seasonal COP

- Heating degree days
- Cooling degree days

$i_{1.5}$ Final to primary energy ratio [c]

- Energy production
- Transmission and distribution
- Storage/end-usage

Scope/Sub-Indicators:

- Residential buildings
- Tertiary buildings
- Municipal buildings

- Private transport
- Public transport
- Municipal vehicle fleet

- Buildings
- Transport
- Industry (Non-ETS)
- Public lighting

Main Data Sources:

[a] SEAP/SECAP and statistical yearbooks

[b] SWERA database

[c] Enerdata

SDEWES Index – Dimension 2

Penetration of Energy and CO_2 Saving Measures (D_2)

Indicators:

$i_{2.1}$ Action Plan for Energy and CO_2 Emissions [a]

$i_{2.2}$ Energy system characteristics [a]

$i_{2.3}$ Energy savings in buildings [a]

$i_{2.4}$ Density of public transport network [b]

$i_{2.5}$ Efficient public lighting armatures [a]

Scope/Sub-Indicators:

- SEAP/SECAP
- Equivalent strategy

- District heating/cooling (DH/C)
- Combined heat and power
- Integration of multiple sources
- Low temperature DH/C network
- Renewable power to hydrogen (P2G)

- Refurfishment of buildings
- Net-zero energy buildings/districts

- Total urban rail per km^2
- Daily usership per km
- Bicycle sharing stations

- Solid-state lighting
- Solar energy based armatures

Main Data Sources:

[a] SEAP/SECAP and local souces

[b] Local public transport sources and World Metro Statistics

SDEWES Index – Dimension 3

Renewable Energy Potential and Utilization (D_3)

Indicators:

$i_{3.1}$ Solar energy potential (Wh/m²/day) [a]

$i_{3.2}$ Wind energy potential (m/s) [b]

$i_{3.3}$ Geothermal energy potential (mW/m²) [c]

$i_{3.4}$ Renewable energy in electricity production (%) [d]

$i_{3.5}$ Green energy share in transport (%) [e]

- Biofuel blends
- Electricity (with > 45% RE share)

Scope/Sub-Indicators:

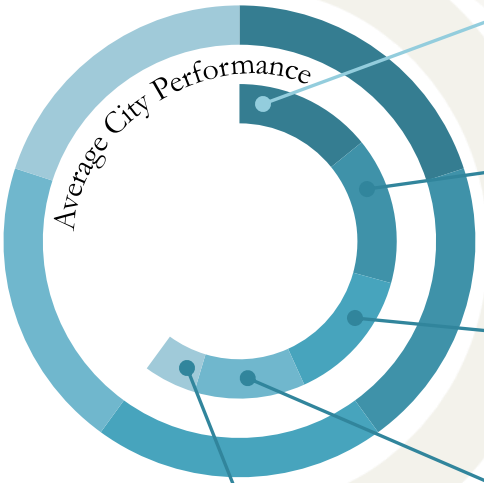
- Irradiation on optimally inclined plane
- Average wind speed at 50 m height
- Mean heat-flow density
- Solar, wind, geothermal, bioenergy, hydropower

Main Data Sources:

[a] JRC PVGIS
[b] IRENA/DTU
[c] IRENA/GeoDH
[d] Enerdata and/or local sources
[e] IEA and/or local sources

SDEWES Index – Dimension 4

Water Usage and Environmental Quality (D_4)



Indicators:

Scope/Sub-Indicators:

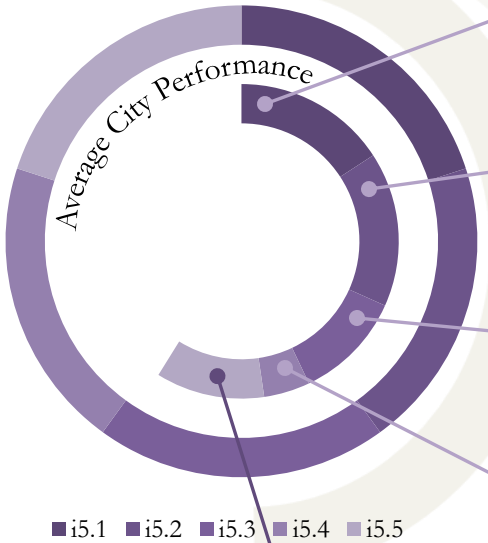
- $i_{4.1}$ Water consumption per capita (m^3/year) [a]
  - Water footprint of domestic blue water consumption
- $i_{4.2}$ Water quality index (/100) [b]
  - Dissolved oxygen
  - pH level
  - Conductivity
  - Nitrogen
  - Phosphorous
- $i_{4.3}$ Annual mean PM_{10} concentration ($\mu g/m^3$) [c]
  - Urban monitoring stations
- $i_{4.4}$ Ecological footprint per capita (gha) [d]
  - Demand for land across six categories
- $i_{4.5}$ Biocapacity per capita (gha) [d]
  - Natural regenerative capacity

Main Data Sources:

[a] Water Footprint Network and related sources
[b] Global Water Quality Index (Srebotnjak *et al.*)
[c] WHO Global Urban Ambient Air Pollution Database
[d] Global Footprint Network; Baabou *et al.* (Mediterranean cities)

SDEWES Index – Dimension 5

CO_2 Emissions and Industrial Profile (D_5)



Indicators:

$i_{5.1}$ CO_2 emissions of buildings (t CO_2) [a]

$i_{5.2}$ CO_2 emissions of transport (t CO_2) [a]

$i_{5.3}$ Average CO_2 intensity (t CO_2/MWh) [a]

$i_{5.4}$ Number of CO_2 intense industries [b]

$i_{5.5}$ Airport ACA level and measures [c]

Airport Carbon Accreditation (ACA)

Scope/Sub-Indicators:

- Residential buildings
- Tertiary buildings
- Municipal buildings

- Private transport
- Public transport
- Municipal vehicle fleet

- Energy related CO_2 emissions
- Waste and wastewater treatment

- Energy intense industries included in EU ETS

- Mapping CO_2 emissions
- Mitigation/optimization
- Renewable energy measures
- Landside/ground handling/airside
- Airports < 150,000 PAX

Main Data Sources:

[a] SEAP and statistical yearbooks

[b] Sectoral reports, Peta 4.2

[c] Airports Council International

SDEWES Index – Dimension 6

Urban Planning and Social Welfare (D_6)

Indicators:

$i_{6.1}$ Waste and wastewater management [a]

- Recycling and compositing share
- Waste generated per capita (kg)
- WWTD compliance (BOD, COD, TSS)
- Coverage of wastewater treatment

$i_{6.2}$ Compact urban form and green spaces [b]

- Population living in core area(s)
- Urban sprawl index (%)
- Share of green area in urban area / share of impermeable surface area
- Number and area of protected reserves, RAMSAR, national parks

$i_{6.3}$ Gross domestic product per capita [c]

$i_{6.4}$ Inequality adjusted well-being [d]

- Citizen satisfaction with daily experience

$i_{6.5}$ Tertiary education rate (%) [e]

- Attainment of ISCED 5 and 6

Main Data Sources:

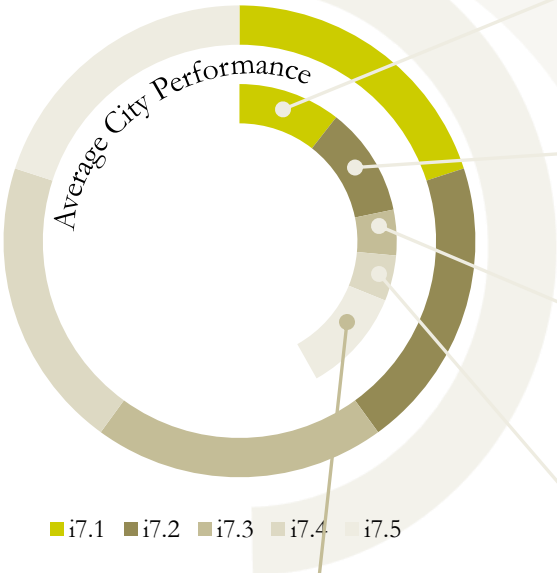
[a] Local/regional data, including Eurostat, Waste Atlas and WWTD database

[b] OECD Metropolitan database, Climate Adaptation Platform, Protected Planet

[c] World Bank/Eurostat [d] Gallop Survey [e] Eurostat/UNESCO

SDEWES Index – Dimension 7

R&D, Innovation and Sustainability Policy (D_7)



Indicators:

$i_{7.1}$ R&D and innovation policy orientation [a]

$i_{7.2}$ National patents in clean technologies [b]

$i_{7.3}$ Local public/private universities [c]
Weighted by inclusion in SCIMago

$i_{7.4}$ National h-index [d]

$i_{7.5}$ Reduction target for CO_2 emissions [c]

- 2020 CO_2 reduction target
- 2030, 2040 and 2050 targets annualized to 2020

Scope/Sub-Indicators:

- R&D and innovation priorities
- Relation to SEAP/SECAP/SUMP
- Gross expenditure on research and development (GERD)/ GDP
  - Y02 and Y04 coded patents (Building technologies, energy generation, transport, smart grid, carbon capture and storage)
  - Share in total national patents
- Public/private universities/institutions
- SCIMago top 1000 institutions *
- Concentration in the city (%)

* Based on research, innovation and societal factors

- Knowledge production including sustainability

Main Data Sources:

[a] JRC R&I Observatory/UNESCO
[b] PatentScope
[c] SciMago Institution Rankings
[d] SciMago Country Rankings
[e] SEAP/SECAP/Local plans

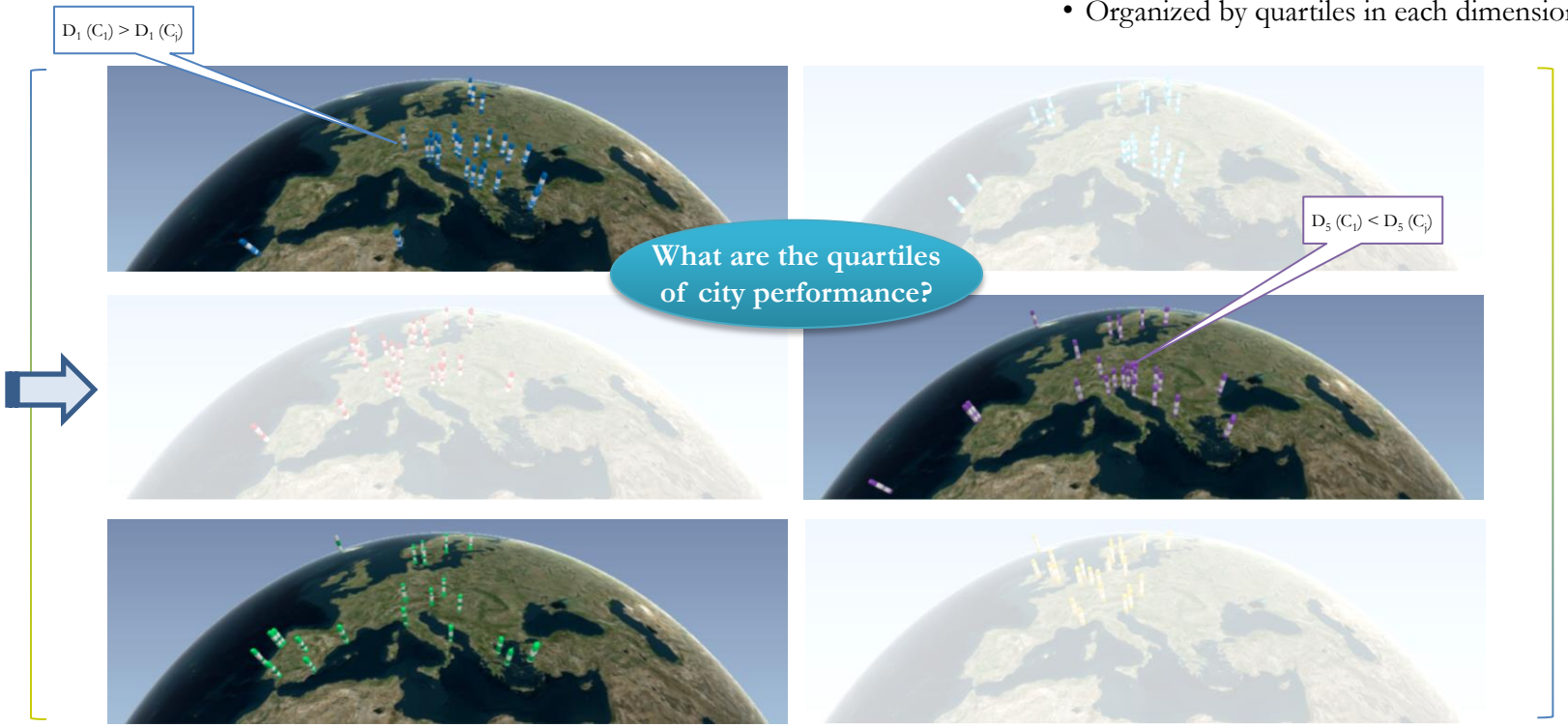
Quartile Performances of the 120 Cities

The synthesis of data from 120 cities around the world metricates a common benchmarking opportunity

The SDEWES Index Atlas

- Normalized results* are mapped spatially
- Organized by quartiles in each dimension

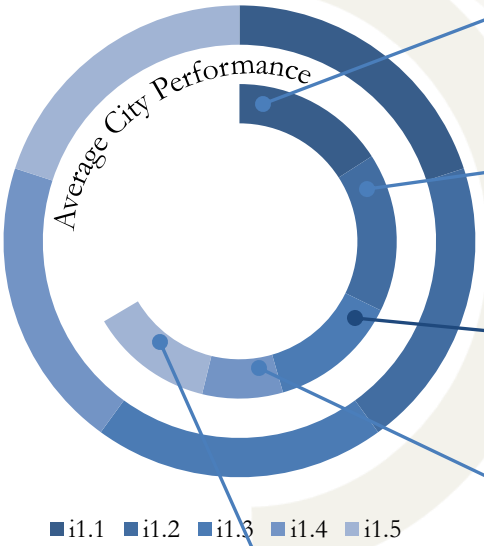
Data for the main indicators: 4,200 inputs



* During the normalization process, winsorization is applied to any outliers in the dataset as identified based on higher order moments

Energy Usage and Climate – D_1

Energy Usage and Climate (D_1)



Indicators:

$i_{1.1}$ Energy usage of buildings (MWh)

$i_{1.2}$ Energy usage of transport (MWh)

$i_{1.3}$ Energy usage per capita (MWh/capita)

$i_{1.4}$ Total degree days (Days °C)

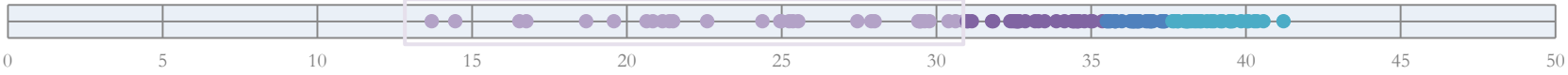
Weighted by average seasonal COP

$i_{1.5}$ Final to primary energy ratio (%)

Average City Performance:

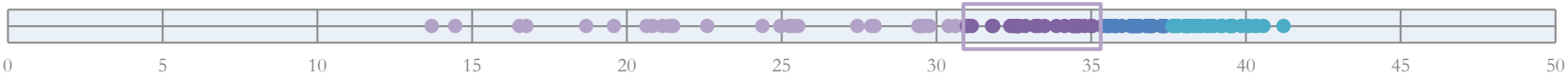
- 7,976,131 MWh
- 4,649,456 MWh
- 14.89 MWh/capita
- 2,548 HDD
- 1,776 CDD
- COP_H=4.0, COP_C=3.5
- 70.9 %

Quartile Performances in D_1



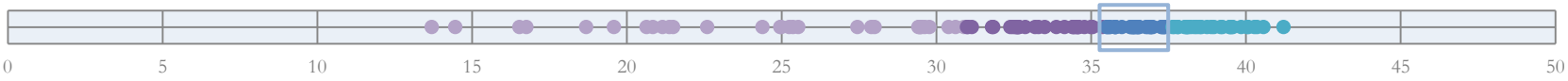
City	D_1	%ΔM	City	D_1	%ΔM	City	D_1	%ΔM
Tianjin	13.698	-61.3	Athens	21.495	-39.3	Gothenburg	28.007	-21.0
London	14.459	-59.2	Hamburg	22.602	-36.2	Amsterdam	29.422	-17.0
Beijing	16.532	-53.4	Christchurch	24.386	-31.2	Frankfurt	29.466	-16.9
Nagoya	16.759	-52.7	Rome	24.958	-29.6	Birmingham	29.474	-16.8
Washington D.C.	18.687	-47.3	Incheon	24.992	-29.5	Warsaw	29.522	-16.7
Cape Town	19.586	-44.7	Grand Lyon	25.250	-28.7	Bangalore	29.627	-16.4
Johannesburg	20.641	-41.8	Istanbul	25.372	-28.4	Antwerp	29.779	-16.0
Berlin	20.842	-41.2	São Paulo	25.543	-27.9	Rio de Janeiro	30.399	-14.2
Paris	21.157	-40.3	Bogotá	27.452	-22.5	Budapest	30.624	-13.6
Cologne	21.375	-39.7	Madrid	27.902	-21.3	Glasgow	30.897	-12.8

Quartile Performances in D_1



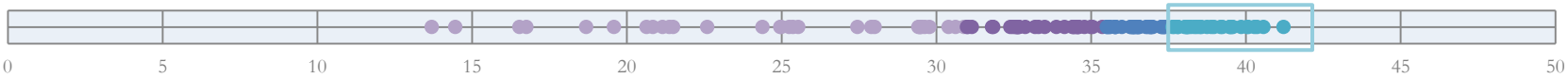
City	D_1	%ΔM	City	D_1	%ΔM	City	D_1	%ΔM
Sofia	30.995	-12.5	Milan	32.637	-7.9	Zaragoza	34.428	-2.9
Belgrade	31.023	-12.5	Grenoble	32.657	-7.8	Pisa	34.460	-2.8
Stockholm	31.151	-12.1	Vienna	32.677	-7.8	Sevilla	34.520	-2.6
Dublin	31.803	-10.3	Nice	32.874	-7.2	Zagreb	34.569	-2.5
Barcelona	31.842	-10.1	Sarajevo	33.194	-6.3	Porto	34.572	-2.4
Bratislava	32.392	-8.6	Lisbon	33.307	-6.0	Lviv	34.609	-2.3
Sydney	32.478	-8.4	Antalya	33.505	-5.5	Florence	34.788	-1.8
Tallinn	32.552	-8.1	Burgas	33.879	-4.4	Bydgoszcz	34.994	-1.3
Leuven	32.582	-8.1	Vila Nova de Gaia	34.145	-3.6	Bijeljina	35.052	-1.1
Aalborg	32.613	-8.0	Bologna	34.404	-2.9	Genoa	35.362	-0.2

Quartile Performances in D_1



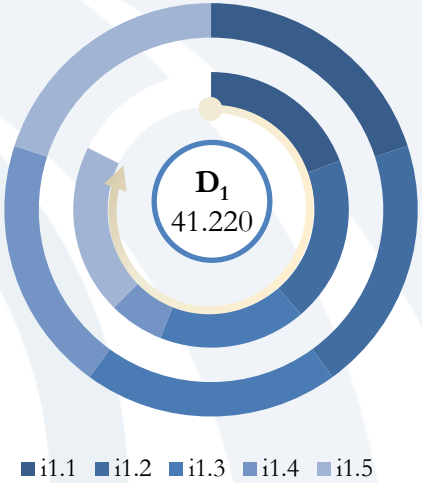
City	D_1	%ΔM	City	D_1	%ΔM	City	D_1	%ΔM
Thessaloniki	35.515	0.2	Valencia	36.350	2.6	Århus	36.839	4.0
Venice	35.520	0.2	Maribor	36.367	2.6	Bilbao	36.914	4.2
Ljubljana	35.587	0.4	Reykjavík	36.370	2.6	Heraklion	36.924	4.2
Málaga	35.617	0.5	Turin	36.401	2.7	Patras	36.954	4.3
Murcia	35.766	0.9	Helsinki	36.462	2.9	Bari	36.995	4.4
Varna	35.790	1.0	Gdynia	36.473	2.9	Batna	37.271	5.2
Naples	35.798	1.0	Volos	36.520	3.1	Niš	37.294	5.2
Braga	35.997	1.6	Kranj	36.539	3.1	Eskişehir Tepebaşı	37.341	5.4
Copenhagen	36.272	2.4	Funchal	36.557	3.2	Ostrava	37.366	5.4
Zenica	36.288	2.4	Pula	36.775	3.8	Dubrovnik	37.390	5.5

Quartile Performances in D_1



City	D_1	%ΔM	City	D_1	%ΔM	City	D_1	%ΔM
Bornova	37.633	6.2	Celje	38.337	8.2	Ohrid	39.492	11.4
Nitra	37.690	6.4	Velenje	38.418	8.4	Seferihisar	39.549	11.6
Skopje	37.806	6.7	Karşıyaka	38.514	8.7	Cluj-Napoca	39.584	11.7
Bursa Nilüfer	37.806	6.7	Espoo	38.568	8.8	Klagenfurt	39.852	12.5
Pécs	38.027	7.3	Osijek	38.748	9.3	Bregenz	40.042	13.0
Podgorica	38.072	7.4	Riga	38.886	9.7	Rijeka	40.086	13.1
Timişoara	38.093	7.5	Vilnius	38.971	10.0	Karlovac	40.278	13.7
Bucharest*	38.125	7.6	Zadar	39.186	10.6	Braşov	40.368	13.9
Izola	38.136	7.6	Constanţa	39.244	10.7	Salé	40.571	14.5
Kalamariá	38.228	7.9	Sfax	39.483	11.4	Tirana	41.220	16.3

Best Practice Examples from D_1

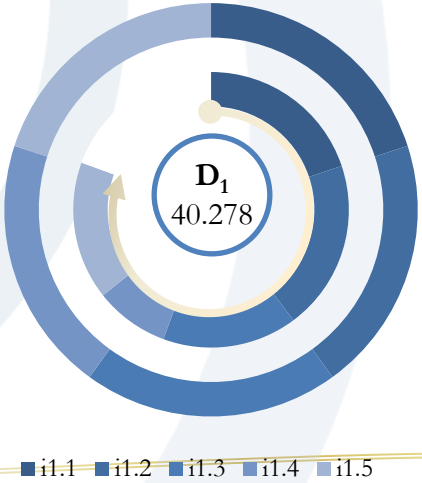


Tirana

Indicators D_1	Value	
i1.1	1,708,236	MWh
i1.2	678,520	MWh
i1.3	7.44	MWh/capita
i1.4	1,082	-
i1.5	90.5	%

Karlovac

Indicators D_1	Value	
i1.1	436,863	MWh
i1.2	126,081	MWh
i1.3	10.21	MWh/capita
i1.4	1,160	-
i1.5	80.3	%



- $i_{1.2}$ reduced by 9.7% from 139,558 MWh with more than a 40% reduction in $i_{1.1}$ from the baseline year

Penetration of Energy and CO_2 Saving Measures – D_2

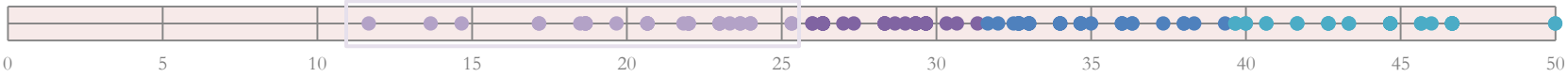
Penetration of Energy and CO_2 Saving Measures (D_2)

Indicators:

Average City Performance:

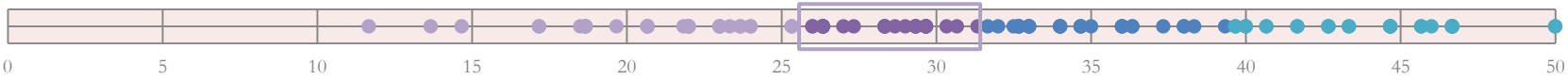
- $i_{2.1}$ Action Plan for Energy and CO_2 Emissions
  - 1.9 / 2.0
- $i_{2.2}$ Energy system characteristics
  - 1.3 / 3.0
  - *Sub-indicators:*
    - Heat only district heating (1)
    - CHP-based district heating (2)
    - Developments for 4GDH (3)
      - 25%, 50% and 75% shares
- $i_{2.3}$ Energy savings in buildings
  - 1.4 / 2.0
- $i_{2.4}$ Density of public transport network
  - 2.6 / 5.0
  - *Sub-indicators:*
    - Urban rail: 0.12 km/km^2
    - 7,828 daily ridership per km
- $i_{2.5}$ Efficient public lighting armatures
  - 1.5 / 2.0

Quartile Performances in D_2



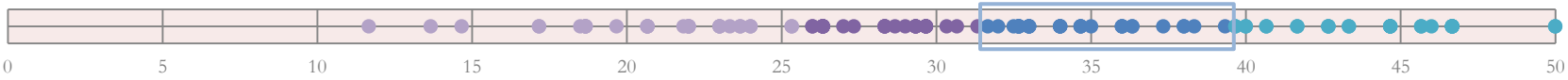
City	D_2	%ΔM	City	D_2	%ΔM	City	D_2	%ΔM
Istanbul	11.667	-63.0	Tirana	19.667	-37.6	Seferihisar	23.000	-27.0
Johannesburg	13.667	-56.6	Bursa Nilüfer	20.667	-34.4	Karlovac	23.000	-27.0
Cape Town	14.667	-53.4	Porto	20.667	-34.4	Constanţa	23.000	-27.0
São Paulo	17.167	-45.5	Vila Nova de Gaia	20.667	-34.4	Belgrade	23.333	-25.9
Rio de Janeiro	17.167	-45.5	Salé	20.667	-34.4	Izola	23.667	-24.9
Bangalore	18.500	-41.3	Tianjin	21.833	-30.7	Eskişehir Tepebaşı	23.667	-24.9
Athens	18.667	-40.7	Zenica	22.000	-30.2	Kranj	24.000	-23.8
Batna	18.667	-40.7	Bijeljina	22.000	-30.2	Bydgoszcz	24.000	-23.8
Funchal	18.667	-40.7	Braga	22.000	-30.2	Podgorica	25.333	-19.6
Sfax	18.667	-40.7	Gdynia	22.000	-30.2	Celje	25.333	-19.6

Quartile Performances in D_2



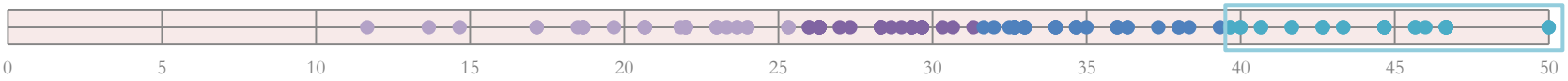
City	D_2	%ΔM	City	D_2	%ΔM	City	D_2	%ΔM
Bilbao	26.000	-17.5	Ohrid	27.000	-14.3	Lviv	29.333	-6.9
Florence	26.000	-17.5	Pisa	27.333	-13.2	Washington D.C.	29.333	-6.9
Zadar	26.333	-16.4	Sarajevo	28.333	-10.1	Bregenz	29.667	-5.8
Heraklion	26.333	-16.4	Karşıyaka	28.333	-10.1	Rijeka	29.667	-5.8
Kalamariá	26.333	-16.4	Cluj-Napoca	28.333	-10.1	Dubrovnik	29.667	-5.8
Bogotá	26.333	-16.4	Ostrava	28.333	-10.1	Pula	29.667	-5.8
Niš	26.333	-16.4	Volos	28.667	-9.0	Patras	29.667	-5.8
Braşov	26.333	-16.4	Christchurch	29.000	-7.9	Antalya	30.333	-3.7
Nitra	26.333	-16.4	Sevilla	29.333	-6.9	Bari	30.667	-2.6
Murcia	26.333	-16.4	Timişoara	29.333	-6.9	Bornova	31.333	-0.5

Quartile Performances in D_2



City	D_2	%ΔM	City	D_2	%ΔM	City	D_2	%ΔM
Venice	31.667	0.5	Velenje	33.000	4.8	Sofia	36.000	14.3
Varna	32.000	1.6	Klagenfurt	33.000	4.8	Bratislava	36.000	14.3
Beijing	32.500	3.2	Osijek	34.000	7.9	Riga	36.000	14.3
Málaga	32.667	3.7	Pécs	34.000	7.9	Thessaloniki	36.333	15.3
Grenoble	32.667	3.7	Bologna	34.000	7.9	Reykjavík	36.333	15.3
Antwerp	32.667	3.7	Aalborg	34.000	7.9	Leuven	37.333	18.5
Dublin	32.667	3.7	Rome	34.667	10.1	Nagoya	38.000	20.6
Vilnius	32.667	3.7	Valencia	34.667	10.1	Madrid	38.000	20.6
Skopje	33.000	4.8	Nice	34.667	10.1	Sydney	38.333	21.7
Burgas	33.000	4.8	Naples	35.000	11.1	Glasgow	39.333	24.9

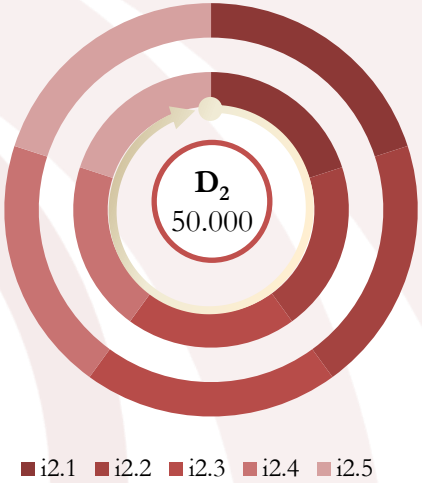
Quartile Performances in D_2



City	D_2	%ΔM	City	D_2	%ΔM	City	D_2	%ΔM
Espoo	39.667	25.9	Gothenburg	42.667	35.4	Århus	46.000	46.0
Maribor	39.667	25.9	Amsterdam	43.333	37.6	Barcelona	46.667	48.1
Milan	40.000	27.0	Helsinki	43.333	37.6	Paris	46.667	48.1
Warsaw	40.000	27.0	Zagreb	44.667	41.8	Vienna	46.667	48.1
Ljubljana	40.667	29.1	Cologne	44.667	41.8	Budapest	46.667	48.1
Tallinn	40.667	29.1	Frankfurt	44.667	41.8	Turin	46.667	48.1
Genoa	41.667	32.3	Grand Lyon	44.667	41.8	Berlin	46.667	48.1
Birmingham	41.667	32.3	Hamburg	44.667	41.8	London	46.667	48.1
Incheon	42.667	35.4	Bucharest*	45.667	45.0	Stockholm	50.000	58.7
Zaragoza	42.667	35.4	Lisbon	45.667	45.0	Copenhagen	50.000	58.7

Best Practice Examples from D_2

- District heating coverage is 98%
- The suburbs of the city are renovated for low temperature district heating network



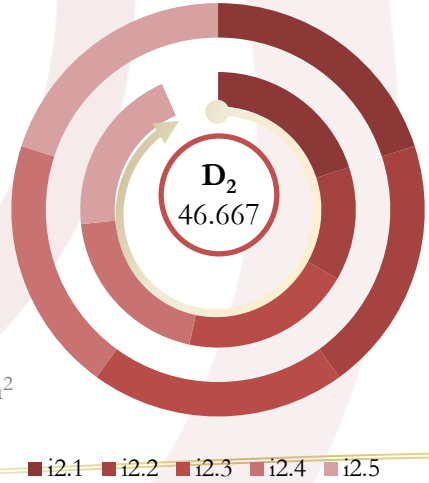
Copenhagen

Indicators D_2	Value
i2.1	2.0
i2.2	3.0
i2.3	2.0
i2.4	5.0
i2.5	2.0

Budapest

Indicators D_2	Value
i2.1	2.0
i2.2	2.0
i2.3	2.0
i2.4	5.0
i2.5	2.0

- Urban rail density 0.37 km/km^2
- Daily ridership: 25,100 per km



Renewable Energy Potential and Utilization – D_3

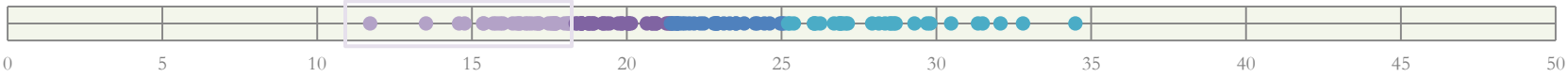
Renewable Energy Potential and Utilization (D_3)

Indicators:

Average City Performance:

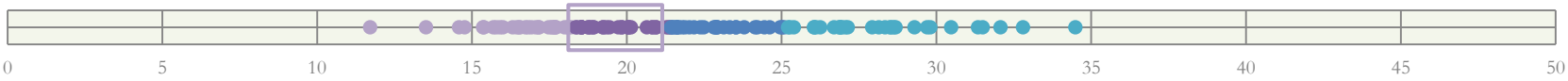
$i_{3.1}$ Solar energy potential (Wh/m²/day)	• 4535 Wh/m²/day
$i_{3.2}$ Wind energy potential (m/s)	• 4.7 m/s
$i_{3.3}$ Geothermal energy potential (mW/m²)	• 67 mW/m²
$i_{3.4}$ Renewable energy in electricity production (%)	• 37.15 %
$i_{3.5}$ Green energy share in transport (%)	• 3.53 %

Quartile Performances in D_3



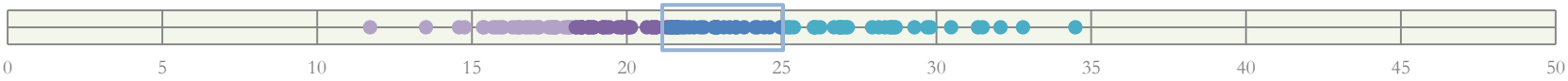
City	D_3	%ΔM	City	D_3	%ΔM	City	D_3	%ΔM
Lviv	11.716	-45.3	Warsaw	16.319	-23.8	Turin	17.477	-18.4
Tallinn	13.521	-36.9	Bologna	16.449	-23.2	Washington D.C.	17.579	-17.9
Birmingham	14.588	-31.9	Beijing	16.522	-22.9	London	17.605	-17.8
Tianjin	14.767	-31.1	Zenica	16.561	-22.7	Brașov	17.673	-17.5
Bydgoszcz	15.364	-28.3	Johannesburg	16.734	-21.9	Venice	17.709	-17.3
Sarajevo	15.393	-28.1	Timișoara	16.814	-21.5	Kranj	17.717	-17.3
Bangalore	15.692	-26.7	Batna	16.921	-21.0	Skopje	17.995	-16.0
Bogotá	15.786	-26.3	Glasgow	17.065	-20.3	Ljubljana	18.098	-15.5
Incheon	15.909	-25.7	Velenje	17.150	-19.9	Rijeka	18.125	-15.4
Vilnius	16.005	-25.3	Maribor	17.177	-19.8	Izola	18.205	-15.0

Quartile Performances in D_3



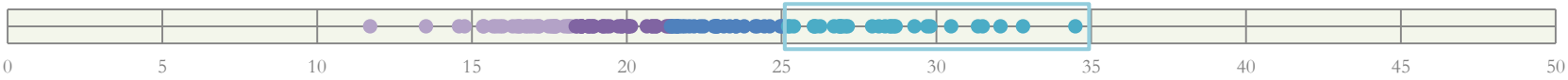
City	D_3	%ΔM	City	D_3	%ΔM	City	D_3	%ΔM
Bilbao	18.356	-14.3	Belgrade	18.938	-11.6	Bijeljina	20.071	-6.3
Berlin	18.406	-14.1	Celje	19.228	-10.2	Salé	20.140	-6.0
Podgorica	18.538	-13.5	Kalamariá	19.254	-10.1	Espoo	20.650	-3.6
Ohrid	18.544	-13.4	Dublin	19.350	-9.7	Hamburg	20.819	-2.8
Milan	18.546	-13.4	Thessaloniki	19.448	-9.2	Pécs	20.842	-2.7
Varna	18.552	-13.4	Paris	19.728	-7.9	Christchurch	20.947	-2.2
Ostrava	18.755	-12.4	Zadar	19.841	-7.4	Amsterdam	20.952	-2.2
Budapest	18.776	-12.4	Sofia	19.847	-7.4	Riga	21.287	-0.6
Nagoya	18.840	-12.1	Cluj-Napoca	20.021	-6.5	Sfax	21.351	-0.3
Gdynia	18.914	-11.7	Burgas	20.061	-6.4	Bursa Nilüfer	21.412	-0.05

Quartile Performances in D_3



City	D_3	%ΔM	City	D_3	%ΔM	City	D_3	%ΔM
Nitra	21.432	0.05	Genoa	22.180	3.5	Bucharest*	23.530	9.8
Niš	21.490	0.3	Florence	22.380	4.1	Cape Town	23.539	9.9
Antwerp	21.506	0.4	Grenoble	22.490	4.5	Rome	23.796	11.1
Cologne	21.600	0.8	Eskişehir Tepebaşı	22.822	5.0	Antalya	24.151	12.7
Pula	21.631	1.0	Patras	22.863	6.5	Nice	24.218	13.1
Naples	21.635	1.0	Karlovac	22.895	6.7	Málaga	24.450	14.1
Istanbul	21.687	1.2	Leuven	22.925	6.9	Zagreb	24.620	14.9
Bratislava	21.795	1.7	Sydney	22.931	7.0	Tirana	24.959	16.5
Funchal	21.884	2.2	Zaragoza	23.139	7.0	Heraklion	25.018	16.8
Frankfurt	22.026	2.8	Constanţa	23.328	7.9	Dubrovnik	25.084	17.1

Quartile Performances in D_3



City	D_3	%ΔM	City	D_3	%ΔM	City	D_3	%ΔM
Murcia	25.214	17.7	Braga	26.905	25.6	Bregenz	28.684	33.9
Osijek	25.272	18.0	Aalborg	26.958	25.8	Gothenburg	29.294	36.8
Grand Lyon	25.402	18.6	Copenhagen	27.069	26.4	Valencia	29.707	38.7
Helsinki	26.055	21.6	Athens	27.139	26.7	Seferihisar	29.809	39.2
Århus	26.056	21.6	Porto	27.932	30.4	Barcelona	30.480	42.3
Madrid	26.115	21.9	Vienna	28.147	31.4	Lisbon	31.348	46.3
Bari	26.254	22.6	Sevilla	28.344	32.3	Stockholm	31.500	47.0
Klagenfurt	26.699	24.6	Vila Nova de Gaia	28.500	33.0	Reykjavík	32.076	49.7
Pisa	26.852	25.3	Bornova	28.543	33.2	São Paulo	32.799	53.1
Volos	26.901	25.6	Karşıyaka	28.627	33.6	Rio de Janeiro	34.494	61.0

Best Practice Examples from D_3

Rio de Janeiro

Indicators D_3	Value	
i3.1	5910	Wh/m²/day
i3.2	4.1	m/s
i3.3	56	mW/m²
i3.4	81.19	%
i3.5	17.87	%

- $i_{3.4}$ improved from 73.86 % in 2015 (+9.9%)

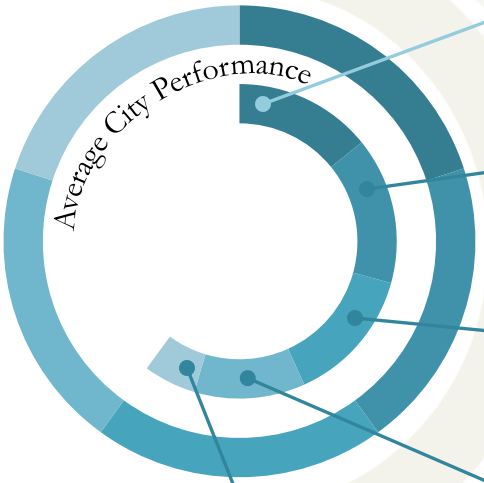
Reykjavík

Indicators D_3	Value	
i3.1	2640	Wh/m²/day
i3.2	8.0	m/s
i3.3	310	mW/m²
i3.4	100.00	%
i3.5	2.50	%

- Winsorized value for $i_{3.3}$ is 128 mW/m²

Water Usage and Environmental Quality – D_4

Water Usage and Environmental Quality (D_4)

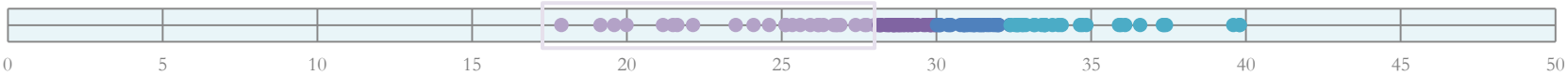


Indicators:

Average City Performance:

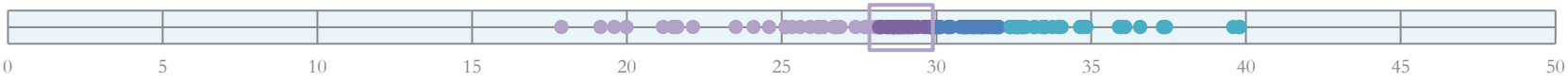
$i_{4.1}$ Water consumption per capita (m^3/cap/year)	• 9.8 m^3/capita/year
$i_{4.2}$ Water quality index (/100)	• 84.0 / 100
$i_{4.3}$ Annual mean PM_{10} concentration ($\mu g/m^3$)	• 30.7 $\mu g/m^3$
$i_{4.4}$ Ecological footprint per capita (gha/capita)	• 4.30 gha / capita
$i_{4.5}$ Biocapacity per capita (gha/capita)	• 2.70 gha / capita

Quartile Performances in D_4



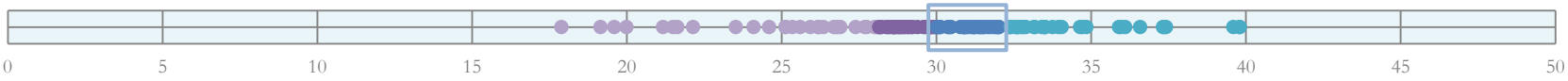
City	D_4	%ΔM	City	D_4	%ΔM	City	D_4	%ΔM
Batna	17.890	-40.4	Lviv	24.599	-18.0	Patras	26.764	-10.8
Skopje	19.149	-36.2	Antwerp	25.131	-16.2	Milan	26.802	-10.7
Ostrava	19.597	-34.7	Istanbul	25.133	-16.2	Bornova	26.902	-10.3
Johannesburg	19.993	-33.4	Leuven	25.351	-15.5	Bogotá	27.393	-8.7
Incheon	21.172	-29.4	Nagoya	25.605	-14.7	Vienna	27.690	-7.7
Washington D.C.	21.493	-28.4	Athens	25.932	-13.6	Bursa Nilüfer	27.755	-7.5
Sfax	21.635	-27.9	Bangalore	26.179	-12.7	Sarajevo	28.008	-6.6
Beijing	22.140	-26.2	Antalya	26.206	-12.7	Volos	28.052	-6.5
Tianjin	23.521	-21.6	Turin	26.355	-12.2	Klagenfurt	28.128	-6.2
Zenica	24.095	-19.7	Cape Town	26.691	-11.0	Rome	28.147	-6.2

Quartile Performances in D_4



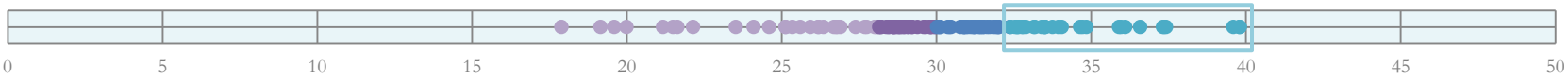
City	D_4	%ΔM	City	D_4	%ΔM	City	D_4	%ΔM
Sevilla	28.153	-6.2	Bari	28.693	-4.4	Nitra	29.220	-2.6
Barcelona	28.208	-6.0	Bregenz	28.778	-4.1	Amsterdam	29.396	-2.0
Venice	28.218	-5.9	Bologna	28.786	-4.1	Heraklion	29.587	-1.4
Nice	28.382	-5.4	Pisa	28.839	-3.9	Bilbao	29.659	-1.1
Paris	28.452	-5.2	Varna	28.875	-3.8	Madrid	29.786	-0.7
Málaga	28.486	-5.1	Grand Lyon	28.948	-3.5	Thessaloniki	29.820	-0.6
Murcia	28.605	-4.7	Eskişehir Tepebaşı	28.978	-3.4	Kalamariá	29.820	-0.6
Florence	28.606	-4.7	Genoa	29.083	-3.1	Bydgoszcz	29.869	-0.4
Grenoble	28.624	-4.6	Bratislava	29.104	-3.0	Valencia	29.947	-0.2
Naples	28.662	-4.5	Reykjavík	29.213	-2.6	Constanţa	29.976	-0.1

Quartile Performances in D_4



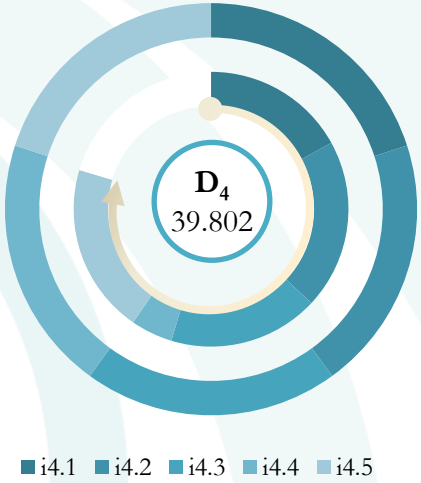
City	D_4	%ΔM	City	D_4	%ΔM	City	D_4	%ΔM
Frankfurt	30.030	0.1	Hamburg	30.903	3.0	Cluj-Napoca	31.511	5.0
Zaragoza	30.073	0.2	Bucharest*	30.959	3.2	Osijek	31.530	5.1
Sofia	30.115	0.4	Copenhagen	31.018	3.4	London	31.644	5.5
Warsaw	30.137	0.4	Porto	31.122	3.7	Vila Nova de Gaia	31.723	5.7
Cologne	30.376	1.2	Zagreb	31.191	4.0	Funchal	31.842	6.1
Berlin	30.426	1.4	Celje	31.232	4.1	Århus	31.920	6.4
Salé	30.476	1.6	Seferihisar	31.242	4.1	Ljubljana	31.976	6.6
Tirana	30.779	2.6	Burgas	31.353	4.5	Braşov	32.016	6.7
Karşıyaka	30.879	2.9	Timişoara	31.421	4.7	Kranj	32.019	6.7
Maribor	30.889	3.0	Aalborg	31.432	4.8	Bijeljina	32.380	7.9

Quartile Performances in D_4



City	D_4	%ΔM	City	D_4	%ΔM	City	D_4	%ΔM
Belgrade	32.402	8.0	Niš	33.406	11.3	Ohrid	35.905	19.7
Sydney	32.548	8.5	Birmingham	33.502	11.7	Vilnius	35.968	19.9
Velenje	32.606	8.7	Pécs	33.509	11.7	Stockholm	36.104	20.3
Karlovac	32.624	8.7	Dublin	33.515	11.7	Tallinn	36.587	21.9
Lisbon	32.668	8.9	Budapest	33.752	12.5	Gothenburg	37.323	24.4
Izola	32.780	9.3	Rijeka	33.950	13.2	Riga	37.363	24.5
Glasgow	32.803	9.3	Podgorica	34.051	13.5	Rio de Janeiro	37.420	24.7
Gdynia	32.896	9.6	Pula	34.645	15.5	São Paulo	39.594	32.0
Braga	33.153	10.5	Zadar	34.724	15.7	Espoo	39.802	32.7
Christchurch	33.188	10.6	Dubrovnik	35.053	16.8	Helsinki	39.802	32.7

Best Practice Examples in D_4



Helsinki

Indicators D_4	Value	
i4.1	6.6	m^3/cap/year
i4.2	99.1	(/100)
i4.3	19.1	µg/m^3
i4.4	6.73	gha
i4.5	13.34	gha

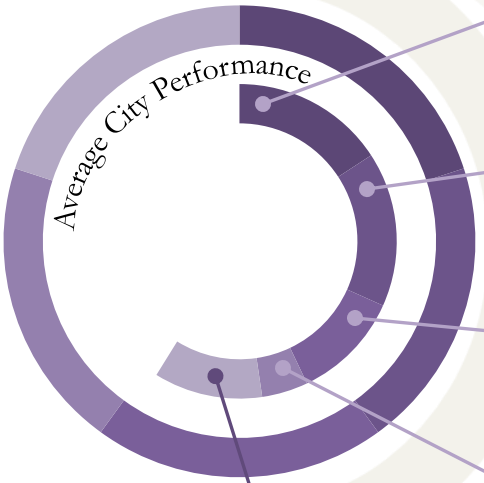
- Winsorized value for $i_{4.5}$ is 8.59

Dubrovnik

Indicators D_4	Value	
i4.1	9.7	m^3/cap/year
i4.2	90.4	(/100)
i4.3	12.66	µg/m^3
i4.4	3.77	gha
i4.5	2.97	gha

CO_2 Emissions and Industrial Profile – D_5

CO_2 Emissions and Industrial Profile (D_5)

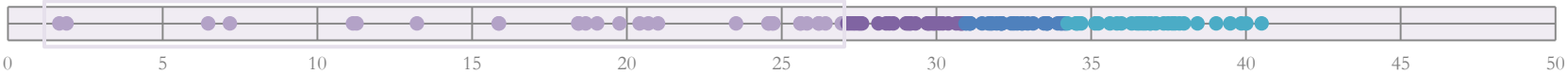


Indicators:

	Average City Performance:
$i_{5.1}$ CO_2 emissions of buildings (t CO_2)	• 2,275,621 t CO_2
$i_{5.2}$ CO_2 emissions of transport (t CO_2)	• 1,093,392 t CO_2
$i_{5.3}$ Average CO_2 intensity (t CO_2/MWh)	• 0.29 t CO_2 / MWh
$i_{5.4}$ Number of CO_2 intense industries	• 3.5 / 8.0
$i_{5.5}$ Airport ACA level and measures	• 1.4 / 6.0

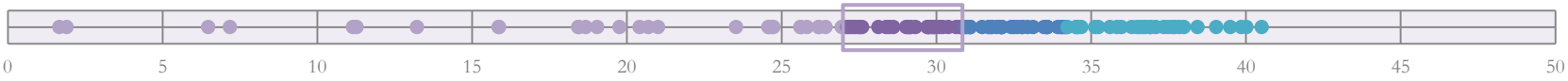
Airport Carbon Accreditation (ACA)

Quartile Performances in D_5



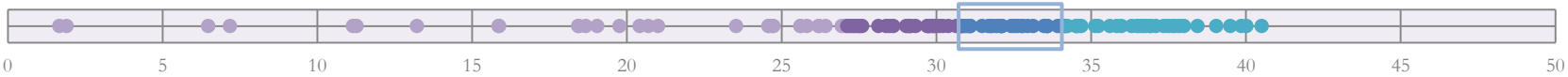
City	D_5	%ΔM	City	D_5	%ΔM	City	D_5	%ΔM
Tianjin	1.667	-94.6	Rio de Janeiro	18.455	-40.3	Madrid	24.700	-20.1
Beijing	1.903	-93.8	Istanbul	18.673	-39.6	Belgrade	24.741	-19.9
Cape Town	6.476	-79.0	Cologne	19.043	-38.4	Ostrava	25.611	-17.1
Nagoya	7.176	-76.8	Hamburg	19.764	-36.0	Sofia	25.619	-17.1
Berlin	11.153	-63.9	Washington D.C.	20.417	-33.9	Genoa	25.823	-16.4
Athens	11.269	-63.5	São Paulo	20.700	-33.0	Turin	26.198	-15.2
Johannesburg	13.221	-57.2	Bogotá	21.008	-32.0	Tallinn	26.208	-15.2
London	15.858	-48.7	Sydney	23.532	-23.8	Antalya	26.422	-14.5
Warsaw	15.873	-48.6	Thessaloniki	24.576	-20.5	Frankfurt	26.947	-12.8
Incheon	18.431	-40.3	Birmingham	24.589	-20.4	Bangalore	27.054	-12.4

Quartile Performances in D_5



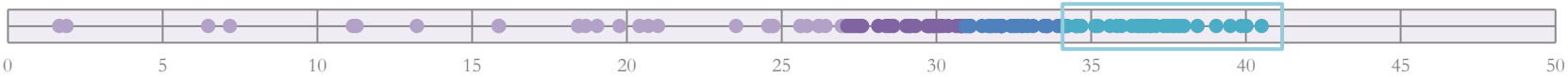
City	D_5	%ΔM	City	D_5	%ΔM	City	D_5	%ΔM
Paris	27.128	-12.2	Zenica	28.615	-7.4	Eskişehir Tepebaşı	29.924	-3.1
Lviv	27.207	-11.9	Salé	29.029	-6.0	Gdynia	29.942	-3.1
Skopje	27.305	-11.6	Budapest	29.088	-5.8	Vienna	30.102	-2.6
Bratislava	27.391	-11.3	Antwerp	29.141	-5.7	Riga	30.208	-2.2
Zaragoza	27.486	-11.0	Valencia	29.179	-5.6	Timişoara	30.387	-1.6
Bydgoszcz	27.548	-10.8	Ljubljana	29.328	-5.1	Sarajevo	30.642	-0.8
Glasgow	27.605	-10.6	Barcelona	29.704	-3.9	Florence	30.756	-0.4
Sevilla	28.131	-8.9	Cluj-Napoca	29.746	-3.7	Lisbon	30.807	-0.3
Braşov	28.378	-8.1	Dublin	29.765	-3.7	Porto	30.823	-0.2
Rome	28.487	-7.8	Murcia	29.840	-3.4	Århus	30.845	-0.2

Quartile Performances in D_5



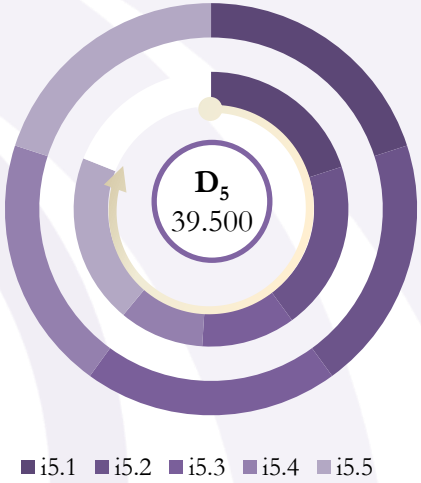
City	D_5	%ΔM	City	D_5	%ΔM	City	D_5	%ΔM
Amsterdam	30.945	0.2	Sfax	32.081	3.8	Málaga	33.128	7.2
Grenoble	30.982	0.3	Grand Lyon	32.106	3.9	Pula	33.480	8.4
Volos	31.078	0.6	Niš	32.113	3.9	Klagenfurt	33.580	8.7
Christchurch	31.096	0.7	Zagreb	32.120	4.0	Varna	33.581	8.7
Bucharest*	31.101	0.7	Podgorica	32.422	4.9	Milan	33.590	8.7
Batna	31.480	1.9	Tirana	32.511	5.2	Vilnius	33.922	9.8
Bilbao	31.687	2.6	Bornova	32.619	5.6	Patras	34.032	10.2
Naples	31.754	2.8	Kalamariá	32.766	6.1	Pécs	34.045	10.2
Bursa Nilüfer	31.801	2.9	Heraklion	32.785	6.1	Nitra	34.135	10.5
Bari	31.950	3.4	Burgas	32.954	6.7	Pisa	34.189	10.7

Quartile Performances in D_5



City	D_5	%ΔM	City	D_5	%ΔM	City	D_5	%ΔM
Zadar	34.242	10.8	Espoo	36.313	17.5	Copenhagen	37.620	21.8
Bologna	34.524	11.7	Helsinki	36.486	18.1	Bregenz	37.709	22.1
Maribor	34.526	11.8	Velenje	36.562	18.3	Dubrovnik	37.856	22.5
Bijeljina	34.585	11.9	Izola	36.672	18.7	Stockholm	38.004	23.0
Rijeka	34.687	12.3	Venice	36.757	19.0	Kranj	38.443	24.4
Osijek	35.136	13.7	Karlovac	36.907	19.5	Leuven	39.048	26.4
Constanța	35.238	14.1	Vila Nova de Gaia	36.921	19.5	Karşıyaka	39.500	27.9
Gothenburg	35.612	15.3	Aalborg	37.095	20.1	Ohrid	39.854	29.0
Celje	35.835	16.0	Braga	37.346	20.9	Nice	40.020	29.5
Funchal	35.983	16.5	Reykjavík	37.491	21.4	Seferihisar	40.514	31.1

Best Practice Examples from D_5



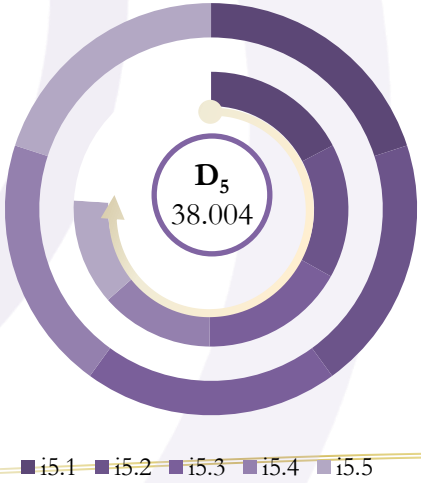
Karşıyaka

Indicators D_5	Value	
i5.1	442,115	t CO_2
i5.2	133,809	t CO_2
i5.3	0.32	t CO_2 / MWh
i5.4	3.0	-
i5.5	0.0	-

Stockholm

Indicators D_5	Value	
i5.1	1,458,000	t CO_2
i5.2	1,116,000	t CO_2
i5.3	0.14	t CO_2 / MWh
i5.4	4.0	-
i5.5	3.0	-

- $i_{5.3}$ improved from 0.15 in previous reporting



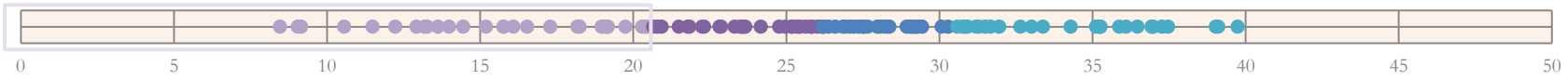
Urban Planning and Social Welfare – D_6

Urban Planning and Social Welfare (D_6)

Indicators:

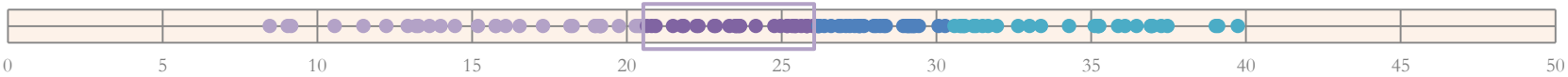
	Average City Performance:	
$i_{6.1}$ Waste and wastewater management	• 4.6 / 6.6	*Sub-indicators:* Waste valorization: • 433 kg waste per cap. 27% recycling and composting
$i_{6.2}$ Compact urban form and green spaces	• 1.9 / 3.0	*Sub-indicators:* • Sprawl index: 0.80% • Impermeable surfaces: 52.7%
$i_{6.3}$ Gross domestic product per capita 201x constant prices	• 31,152 PPP$	
$i_{6.4}$ Inequality adjusted well-being	• 6.9 / 10.0	
$i_{6.5}$ Tertiary education rate (%)	• 34.3 %	

Quartile Performances in D_6



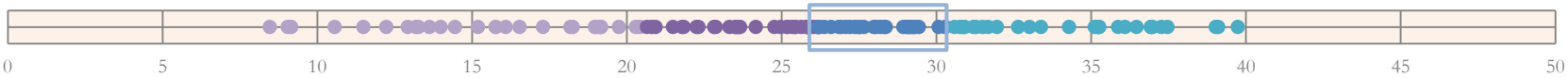
City	D_6	%ΔM	City	D_6	%ΔM	City	D_6	%ΔM
Salé	8.468	-67.6	Podgorica	13.986	-46.5	Johannesburg	18.972	-27.5
Zenica	9.047	-65.4	Eskişehir Tepebaşı	14.449	-44.8	Bursa Nilüfer	18.997	-27.4
Bangalore	9.159	-65.0	Lviv	15.191	-41.9	Seferihisar	19.100	-27.0
Bijeljina	10.566	-59.6	Bornova	15.766	-39.7	São Paulo	19.151	-26.8
Batna	10.690	-59.1	Karşıyaka	15.766	-39.7	Bogotá	19.157	-26.8
Tirana	11.492	-56.1	Tianjin	16.090	-38.5	Rio de Janeiro	19.169	-26.7
Sarajevo	12.232	-53.3	Belgrade	16.539	-36.8	Skopje	19.747	-24.5
Sfax	13.191	-49.6	Antalya	17.294	-33.9	Timişoara	20.292	-22.4
Istanbul	13.269	-49.3	Bucharest*	18.180	-30.5	Constanţa	20.370	-22.1
Niš	13.625	-47.9	Beijing	18.253	-30.2	Cluj-Napoca	20.442	-21.9

Quartile Performances in D_6



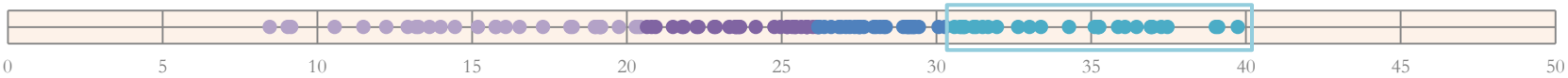
City	D_6	%ΔM	City	D_6	%ΔM	City	D_6	%ΔM
Zadar	20.656	-21.1	Nitra	23.318	-10.9	Heraklion	25.184	-3.8
Pula	20.803	-20.5	Volos	23.517	-10.1	Sevilla	25.349	-3.1
Sofia	20.933	-20.0	Kalamariá	23.517	-10.1	Zagreb	25.440	-2.8
Rijeka	21.492	-17.9	Athens	23.579	-9.9	Bratislava	25.460	-2.7
Cape Town	21.790	-16.7	Budapest	23.629	-9.7	Pécs	25.636	-2.0
Pisa	21.840	-16.5	Karlovac	23.663	-9.6	Málaga	25.813	-1.4
Osijek	22.253	-15.0	Funchal	24.170	-7.6	Zaragoza	25.823	-1.3
Burgas	22.318	-14.7	Lisbon	24.769	-5.3	Florence	25.826	-1.3
Braşov	22.824	-12.8	Riga	24.972	-4.6	Vila Nova de Gaia	26.014	-0.6
Varna	22.875	-12.6	Thessaloniki	25.184	-3.8	Dubrovnik	26.139	-0.1

Quartile Performances in D_6



City	D_6	%ΔM	City	D_6	%ΔM	City	D_6	%ΔM
Genoa	26.193	0.1	Bologna	27.487	5.0	Naples	29.034	11.0
Ostrava	26.193	0.1	Porto	27.533	5.2	Murcia	29.096	11.2
Milan	26.225	0.2	Braga	27.533	5.2	Valencia	29.105	11.2
Celje	26.386	0.8	Vilnius	27.663	5.7	Venice	29.167	11.5
Ohrid	26.602	1.7	Turin	27.978	6.9	Gdynia	29.222	11.7
Patras	26.851	2.6	Barcelona	28.056	7.2	Madrid	29.267	11.9
Nagoya	26.927	2.9	Velenje	28.190	7.7	Bydgoszcz	29.312	12.0
Bari	27.083	3.5	Rome	28.313	8.2	Washington D.C.	29.437	12.5
Tallinn	27.211	4.0	Warsaw	28.369	8.4	Paris	30.079	15.0
Kranj	27.366	4.6	Bilbao	28.936	10.6	Maribor	30.285	15.7

Quartile Performances in D_6



City	D_6	%ΔM	City	D_6	%ΔM	City	D_6	%ΔM
Incheon	30.587	16.9	Frankfurt	32.649	24.8	Århus	36.098	38.0
Izola	30.767	17.6	Ljubljana	33.012	26.2	Reykjavík	36.468	39.4
Grand Lyon	30.815	17.8	Birmingham	33.381	27.6	Espoo	36.931	41.1
Leuven	30.884	18.0	Bregenz	34.289	31.0	Klagenfurt	36.945	41.2
Grenoble	30.920	18.2	Berlin	35.121	34.2	Copenhagen	36.985	41.3
Antwerp	31.201	19.2	Dublin	35.224	34.6	Amsterdam	37.272	42.4
Christchurch	31.286	19.6	Glasgow	35.228	34.6	Vienna	37.471	43.2
Hamburg	31.495	20.4	Sydney	35.251	34.7	Stockholm	39.031	49.2
Cologne	31.678	21.1	Helsinki	35.265	34.8	Gothenburg	39.107	49.5
Nice	31.961	22.1	London	35.874	37.1	Aalborg	39.744	51.9

Best Practice Examples from D_6

Aalborg

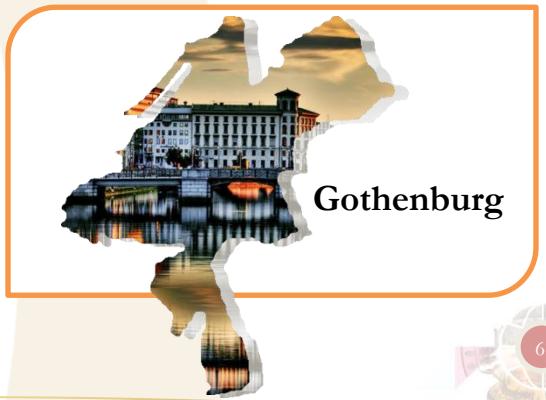
Indicators D_6	Value	
i6.1	5.5	-
i6.2	2.7	-
i6.3	49,696	PPP$
i6.4	7.9	/ 10.0
i6.5	47.7	%

- Recycling and composting: 36%
- Waste per capita: 380 kg
- Green urban area 30.32%
- Impermeable surfaces 26.39%

Gothenburg

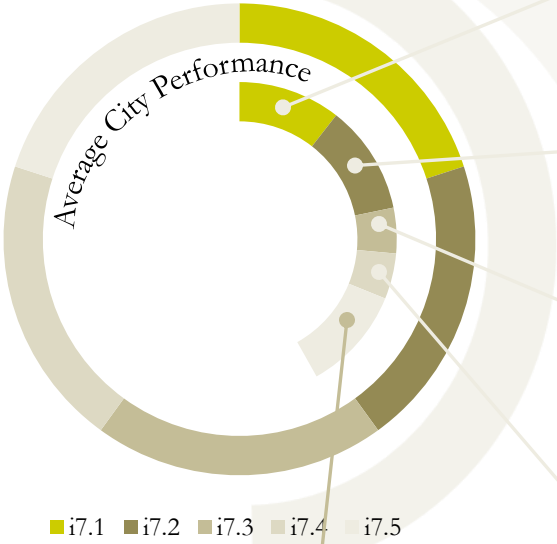
Indicators D_6	Value	
i6.1	5.8	..
i6.2	2.3	..
i6.3	49,175	PPP$
i6.4	7.9	/ 10.0
i6.5	51.0	%

- Sprawl index: -1.97%
- Share of population in core areas: 56.15%



R&D, Innovation and Sustainability Policy – D_7

R&D, Innovation and Sustainability Policy (D_7)

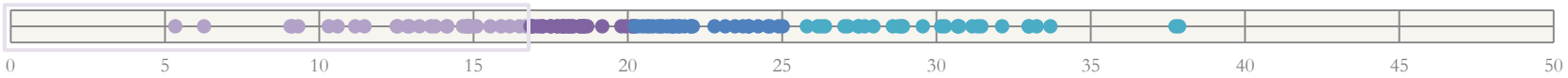


Indicators:

Average City Performance:

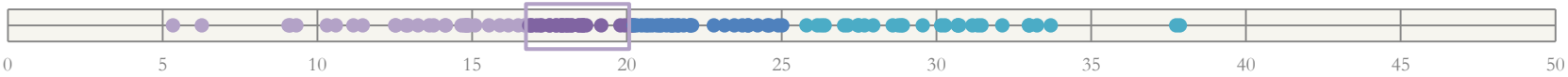
- $i_{7.1}$ R&D and innovation policy orientation — • 2.1 / 3.0
- $i_{7.2}$ National patents in clean technologies — • 1.7 / 3.0
- $i_{7.3}$ Local public/private universities
  Weighted by inclusion in SCIMago — • 8
- $i_{7.4}$ National h-index — • 492
- $i_{7.5}$ Reduction target for CO_2 emissions (%) — • 24 %

Quartile Performances in D_7



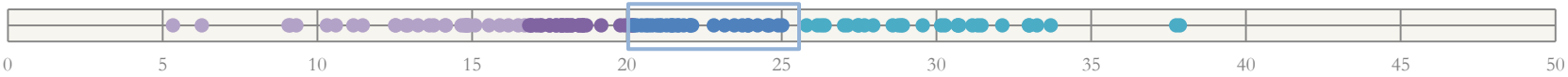
City	D_7	%ΔM	City	D_7	%ΔM	City	D_7	%ΔM
Sfax	5.342	-73.6	Timişoara	12.543	-38.0	Bratislava	14.795	-26.8
Zenica	6.272	-69.0	Patras	12.873	-36.3	Lviv	14.841	-26.6
Bijeljina	9.074	-55.1	Bogotá	12.930	-36.1	Braşov	14.852	-26.6
Sarajevo	9.129	-54.9	Cluj-Napoca	13.257	-34.4	Salé	14.902	-26.3
Podgorica	9.325	-53.9	Skopje	13.622	-32.6	Burgas	15.103	-25.3
Tirana	10.314	-49.0	Volos	13.761	-32.0	Kalamariá	15.547	-23.1
Batna	10.600	-47.6	Maribor	14.127	-30.1	Heraklion	15.896	-21.4
Ohrid	11.170	-44.8	Ostrava	14.159	-30.0	Varna	16.175	-20.0
Constanţa	11.471	-43.3	Thessaloniki	14.658	-27.5	Kranj	16.492	-18.5
Nitra	12.517	-38.1	Tallinn	14.758	-27.0	Christchurch	16.698	-17.4

Quartile Performances in D_7

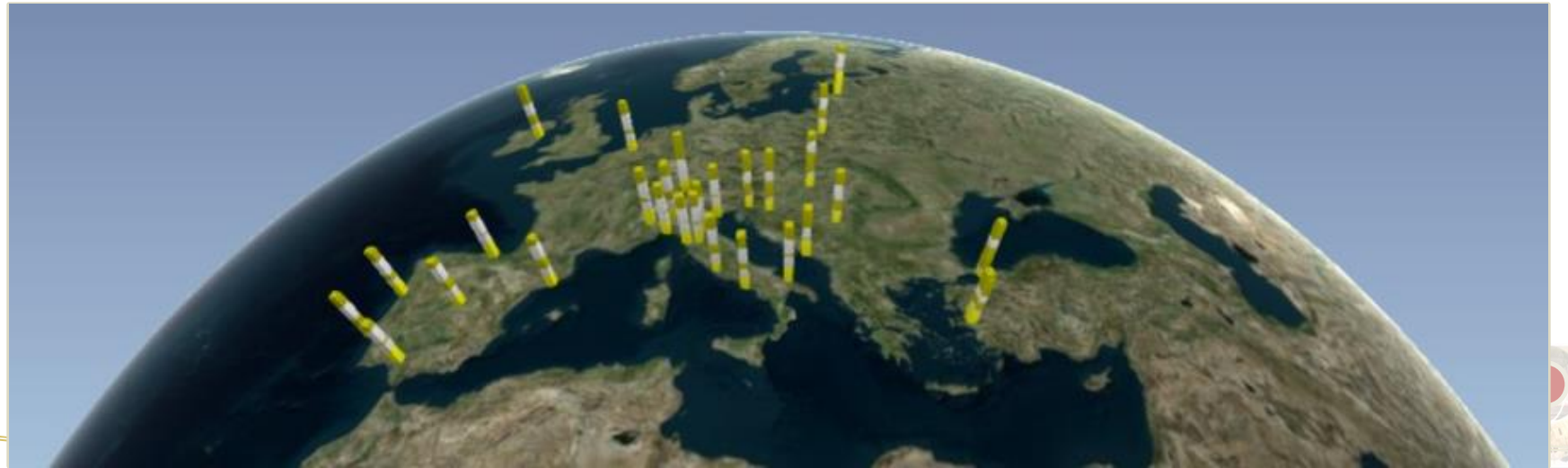


City	D_7	%ΔM	City	D_7	%ΔM	City	D_7	%ΔM
Izola	16.849	-16.7	Karlovac	17.885	-11.6	Eskişehir Tepebaşı	18.569	-8.2
Gdynia	16.905	-16.4	Bursa Nilüfer	17.902	-11.5	Braga	18.586	-8.1
Velenje	16.937	-16.3	Reykjavík	17.908	-11.5	Valencia	18.588	-8.1
Pécs	17.091	-15.5	Cape Town	18.009	-11.0	Osijek	18.686	-7.6
Celje	17.206	-14.9	Seferihisar	18.077	-10.6	Rijeka	19.178	-5.2
Niš	17.257	-14.7	Zadar	18.107	-10.5	Sofia	19.794	-2.1
Vilnius	17.499	-13.5	Antalya	18.212	-9.9	Johannesburg	19.935	-1.4
Málaga	17.516	-13.4	Murcia	18.231	-9.9	Leuven	20.139	-0.4
Bydgoszcz	17.707	-12.4	Funchal	18.452	-8.8	Athens	20.158	-0.3
Zaragoza	17.739	-12.3	Pula	18.464	-8.7	Bucharest*	20.217	-0.03

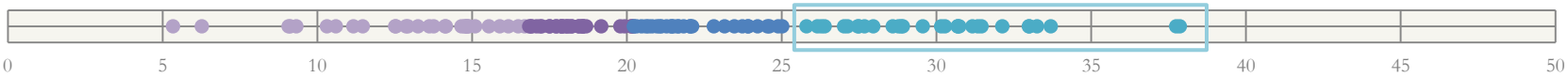
Quartile Performances in D_7



City	D_7	%ΔM	City	D_7	%ΔM	City	D_7	%ΔM
Sevilla	20.231	0.03	Lisbon	21.444	6.0	Ljubljana	23.159	14.5
Bilbao	20.318	0.5	Madrid	21.445	6.0	Milan	23.476	16.1
Warsaw	20.477	1.3	Bornova	21.514	6.4	Karşıyaka	23.736	17.4
Bologna	20.619	2.0	Venice	21.643	7.0	Turin	23.913	18.2
Riga	20.700	2.4	Belgrade	21.677	7.2	Bregenz	23.931	18.3
Dubrovnik	20.821	3.0	Vila Nova de Gaia	21.840	8.0	Naples	24.230	19.8
Florence	20.976	3.7	Bangalore	22.037	9.0	Rome	24.547	21.4
Pisa	21.063	4.2	Budapest	22.059	9.1	Istanbul	24.609	21.7
Antwerp	21.123	4.4	Barcelona	22.112	9.3	Zagreb	24.893	23.1
Genoa	21.286	5.2	Dublin	22.816	12.8	Bari	25.024	23.7



Quartile Performances in D_7



City	D_7	%ΔM	City	D_7	%ΔM	City	D_7	%ΔM
Espoo	25.807	27.6	Glasgow	28.594	41.4	Cologne	31.167	54.1
Grand Lyon	26.160	29.3	Grenoble	28.779	42.3	Incheon	31.346	55.0
Porto	26.285	30.0	Klagenfurt	28.867	42.7	Copenhagen	31.460	55.6
São Paulo	26.393	30.5	Aalborg	28.920	43.0	Nagoya	32.134	58.9
Gothenburg	27.023	33.6	Stockholm	29.563	46.2	Hamburg	32.992	63.1
Nice	27.136	34.2	Washington D.C.	30.159	49.1	Sydney	33.009	63.2
Rio de Janeiro	27.465	35.8	Amsterdam	30.281	49.7	Frankfurt	33.254	64.4
Vienna	27.502	36.0	Beijing	30.695	51.8	Paris	33.699	66.6
Helsinki	27.680	36.9	Tianjin	30.695	51.8	Berlin	37.754	86.7
Birmingham	27.967	38.3	Århus	30.746	52.0	London	37.871	87.3

Best Practice Examples from D_7

London

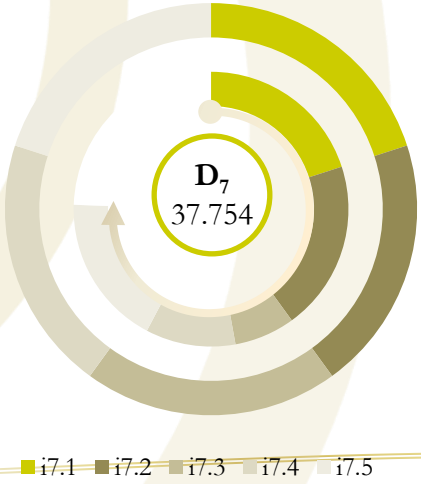
Indicators D_7	Value	
i7.1	2.0	
i7.2	2.5	
i7.3	19	
i7.4	1213	
i7.5	38	%

- GERD / GDP: 1.72 %
- Y02 and Y04 Patents: > 25,000 (3.8 %)
- Prior to SCIMago weighting (i7.3)

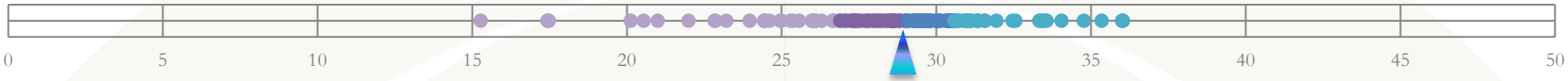
Berlin

Indicators D_7	Value	
i7.1	3.0	
i7.2	3.0	
i7.3	11	
i7.4	1059	
i7.5	40	%

- GERD / GDP: 2.98 %
- Y02 and Y04 Patents: > 150,000 (2.6%)



SDEWES Index Performance of an Average City



SDEWES Index Performance of an Average City
28.441/50.000

R&D, Innovation and Sustainability Policy (D_7)

20.921/50.000 **

Energy Usage and Climate (D_1)

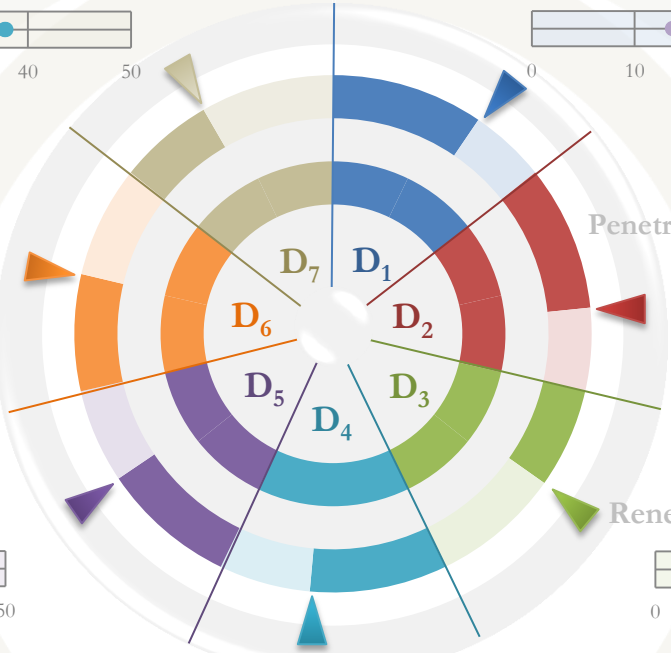
33.255/50.000 *

Urban Planning and Social Welfare (D_6)

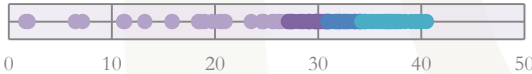
25.479/50.000 **

Penetration of Energy and CO_2 Saving Measures (D_2)

31.901/50.000 **



CO_2 Emissions and Industrial Profile (D_5)



29.426/50.000 *

Renewable Energy Potential and Utilization (D_3)

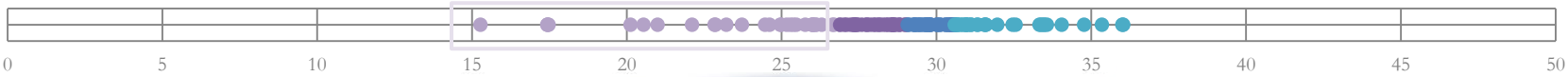
21.851/50.000 **

Water Usage and Environmental Quality (D_4)

30.016/50.000 **

(*) $\alpha = 0.225$
(**) $\alpha = 0.110$

Around the World with the SDEWES Index Atlas



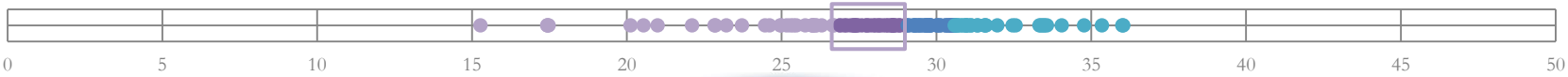
Lower 25% of the City Sample

(Continued)

City	Index	%ΔM
Tianjin	15.277	-47.4
Beijing	17.433	-40.0
Cape Town	17.446	-39.9
Johannesburg	17.479	-39.8
Athens	20.125	-30.7
Istanbul	20.544	-29.3
Nagoya	20.999	-27.7
Bogotá	22.112	-23.9
Bangalore	22.839	-21.4
Washington D.C.	22.870	-21.3
Zenica	23.219	-20.1
Batna	23.722	-18.3
Lviv	24.470	-15.8
Sarajevo	24.617	-15.3
Sfax	24.960	-14.1

City	Index	%ΔM
Belgrade	24.996	-14.0
Warsaw	25.165	-13.4
São Paulo	25.290	-12.9
Incheon	25.388	-12.6
London	25.477	-12.3
Berlin	25.769	-11.3
Rio de Janeiro	25.981	-10.6
Ostrava	26.003	-10.5
Bijeljina	26.021	-10.4
Skopje	26.089	-10.2
Salé	26.129	-10.1
Antalya	26.301	-9.5
Cologne	26.649	-8.3
Sofia	26.701	-8.1
Christchurch	26.873	-7.5

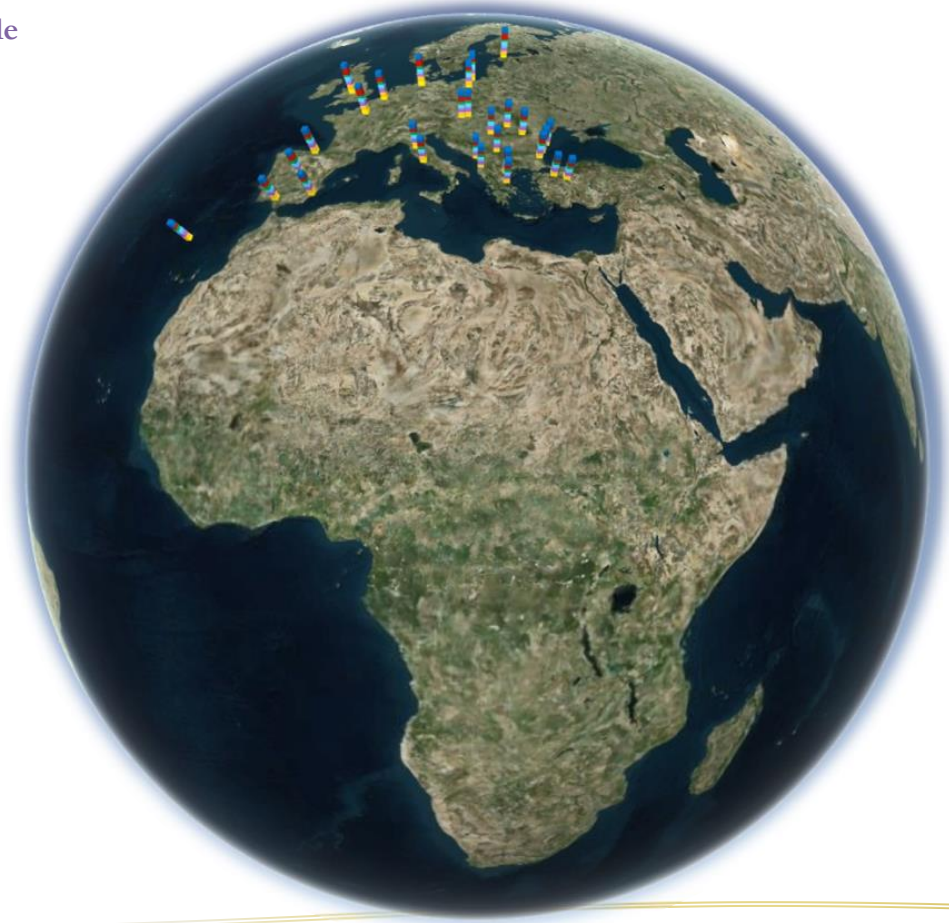
Around the World with the SDEWES Index Atlas



Lower 25-50% of the City Sample

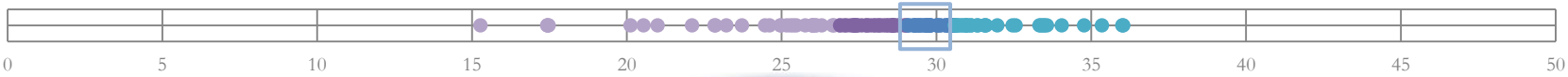
(Continued)

City	Index	%ΔM
Bydgoszcz	26.897	-7.4
Podgorica	27.025	-7.0
Eskişehir Tepebaşı	27.105	-6.7
Hamburg	27.243	-6.2
Tirana	27.326	-5.9
Rome	27.349	-5.9
Thessaloniki	27.374	-5.8
Bursa Nilüfer	27.432	-5.6
Bratislava	27.463	-5.5
Timişoara	27.591	-5.0
Antwerp	27.739	-4.5
Madrid	27.759	-4.4
Tallinn	27.854	-4.1
Niš	27.975	-3.7
Braşov	28.035	-3.5



City	Index	%ΔM
Cluj-Napoca	28.140	-3.1
Gdynia	28.169	-3.0
Paris	28.283	-2.6
Florence	28.384	-2.3
Burgas	28.444	-2.1
Volos	28.536	-1.8
Sevilla	28.584	-1.6
Nitra	28.589	-1.6
Kalamariá	28.593	-1.6
Varna	28.652	-1.4
Constanța	28.674	-1.3
Birmingham	28.810	-0.8
Murcia	28.814	-0.8
Funchal	28.976	-0.3
Bilbao	29.021	-0.1

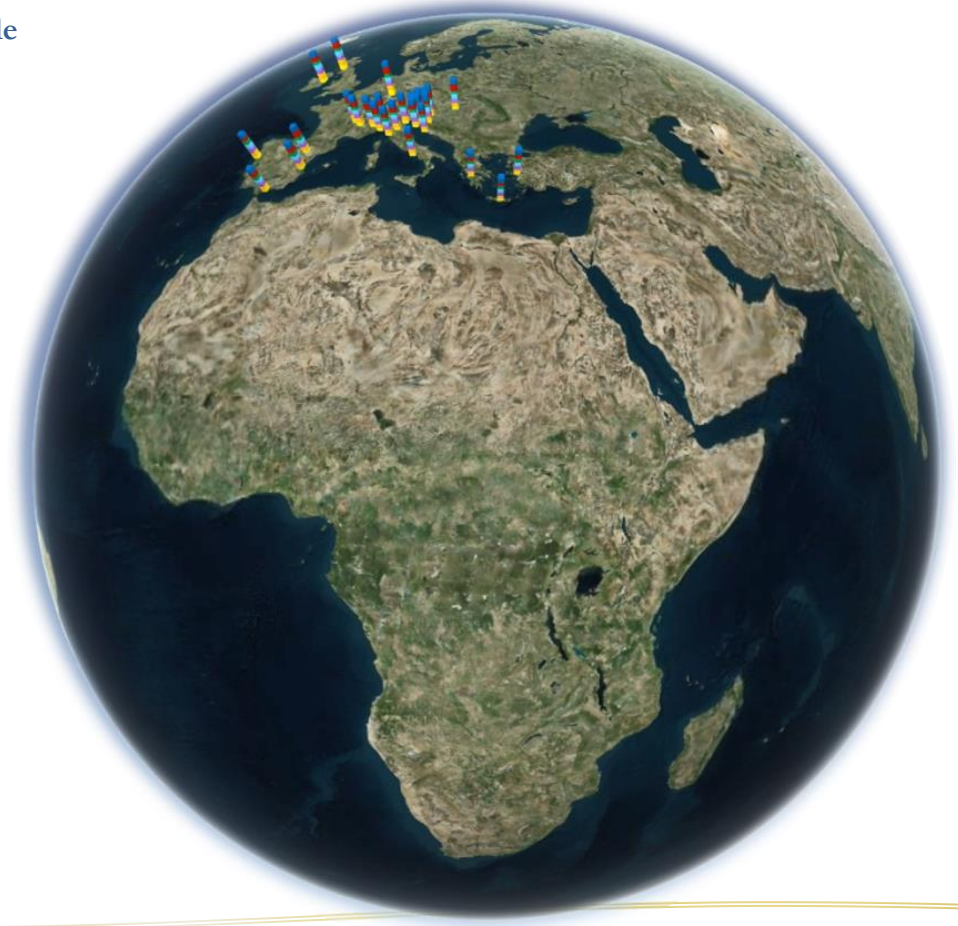
Around the World with the SDEWES Index Performance



Top 50-75% of the City Sample

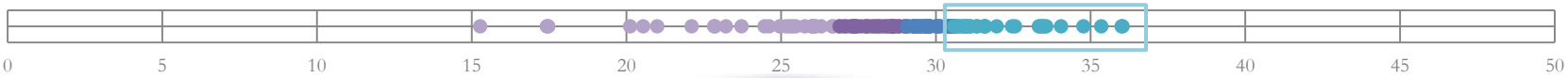
(Continued)

City	Index	%ΔM
Patras	29.078	0.1
Heraklion	29.127	0.3
Genoa	29.259	0.7
Pisa	29.299	0.9
Zaragoza	29.304	0.9
Budapest	29.380	1.1
Porto	29.422	1.3
Bornova	29.478	1.5
Bologna	29.516	1.6
Pula	29.597	1.9
Dublin	29.656	2.1
Málaga	29.663	2.1
Zadar	29.709	2.3
Milan	29.752	2.4
Kranj	29.797	2.6



City	Index	%ΔM
Turin	29.799	2.6
Celje	29.834	2.7
Glasgow	30.012	3.3
Grand Lyon	30.030	3.4
Grenoble	30.110	3.6
Vila Nova de Gaia	30.138	3.7
Izola	30.289	4.3
Rijeka	30.316	4.4
Venice	30.380	4.6
Valencia	30.401	4.7
Naples	30.461	4.9
Sydney	30.475	4.9
Maribor	30.496	5.0
Karlovac	30.591	5.3
Frankfurt	30.594	5.3

Around the World with the SDEWES Index Performance



Top 25% of the City Sample

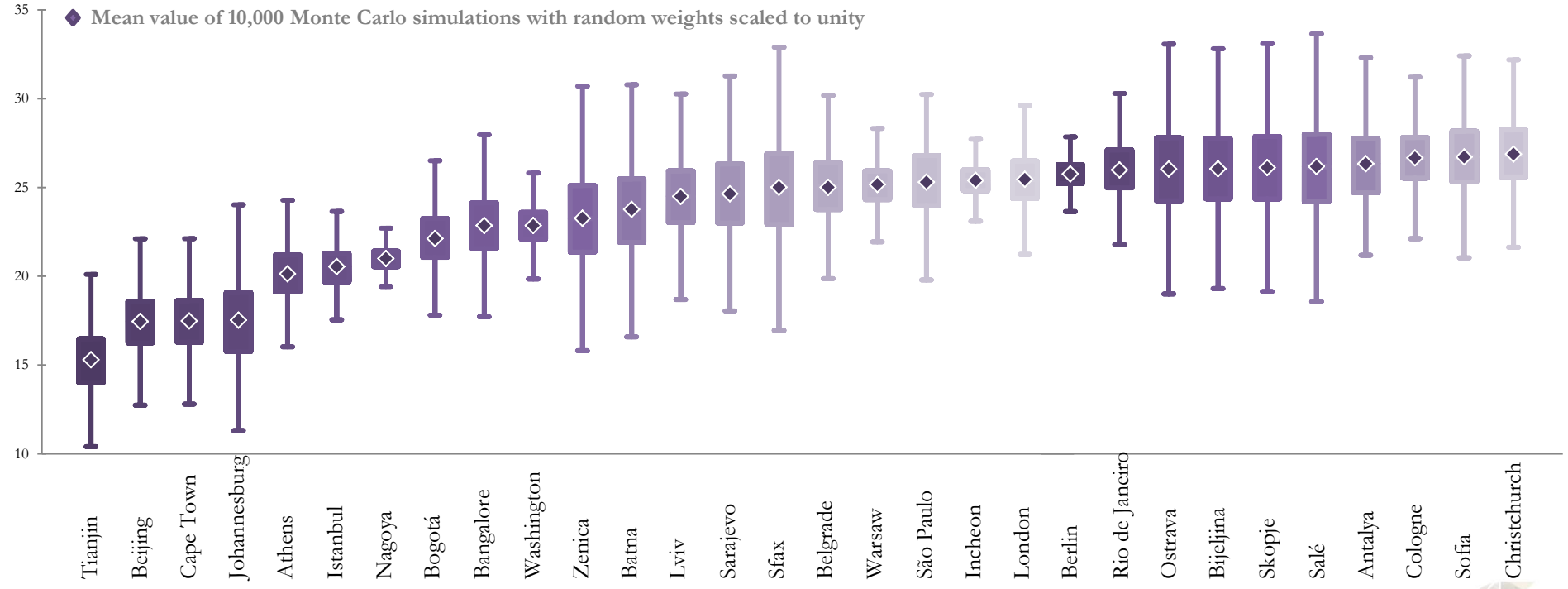
(Continued)

City	Index	%ΔM
Braga	30.595	5.3
Pécs	30.655	5.5
Bari	30.687	5.6
Vilnius	30.704	5.7
Ljubljana	30.797	6.0
Bucharest	30.852	6.2
Velenje	30.947	6.5
Ohrid	30.965	6.6
Barcelona	30.966	6.6
Riga	31.025	6.8
Leuven	31.114	7.1
Osijek	31.134	7.2
Amsterdam	31.311	7.8
Seferihisar	31.344	7.9
Karşıyaka	31.556	8.6

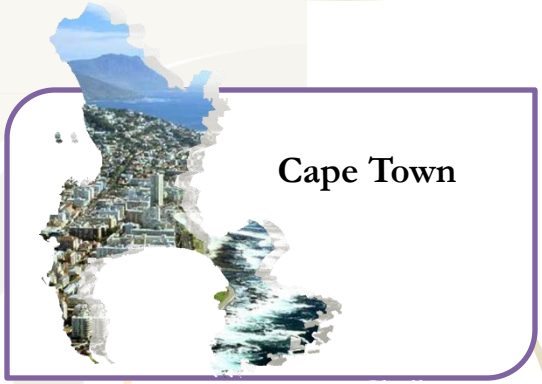
City	Index	%ΔM
Lisbon	31.587	8.7
Zagreb	31.606	8.8
Dubrovnik	31.972	10.1
Nice	32.465	11.8
Vienna	32.561	12.1
Reykjavík	33.333	14.7
Aalborg	33.378	14.9
Klagenfurt	33.454	15.2
Bregenz	33.494	15.3
Gothenburg	33.572	15.6
Århus	34.049	17.2
Espoo	34.774	19.7
Helsinki	35.348	21.7
Stockholm	36.007	24.0
Copenhagen	36.038	24.1

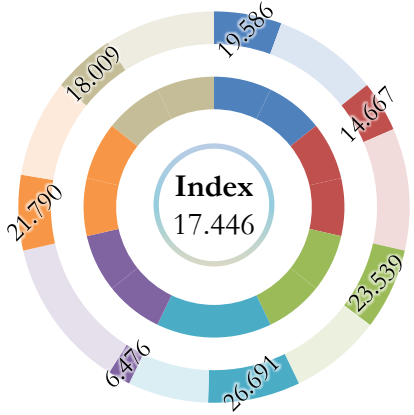
Monte Carlo Simulations – Lower 25% of Cities

SDEWES Index Score (Corresponding to City Ranks 120-91)



Challenged Cities: Challenges in Multiple Dimensions

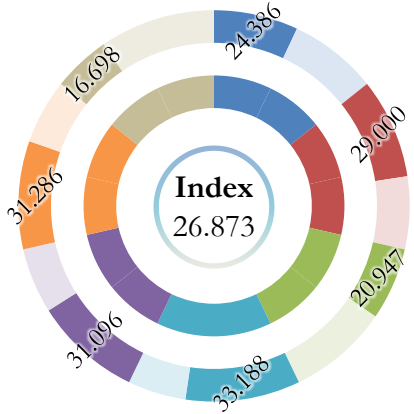




Challenges:

- D_1
- D_2
- D_3
- D_4
- D_5
- D_6
- D_7

D1 D2 D3 D4 D5 D6 D7



Challenges:

- D_1
- D_2
- D_3
- D_7

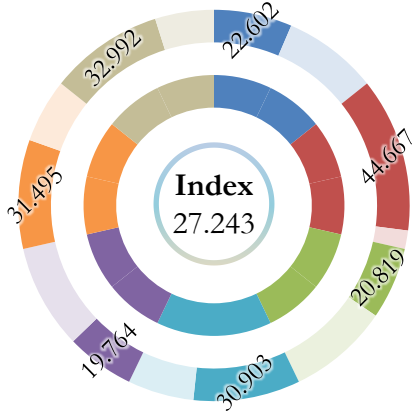
Promising Developments:

Cape Town Energy 2040 Roadmap

Monte Carlo Simulations – Lower 25-50% of Cities

Solution Seeking Cities: Need for Strategic Approaches

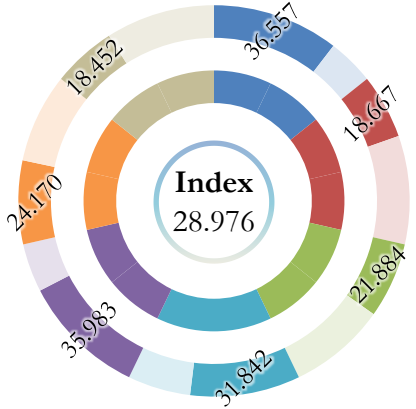
Challenges:
- D_1
- D_3
- D_5



D1 D2 D3 D4 D5 D6 D7

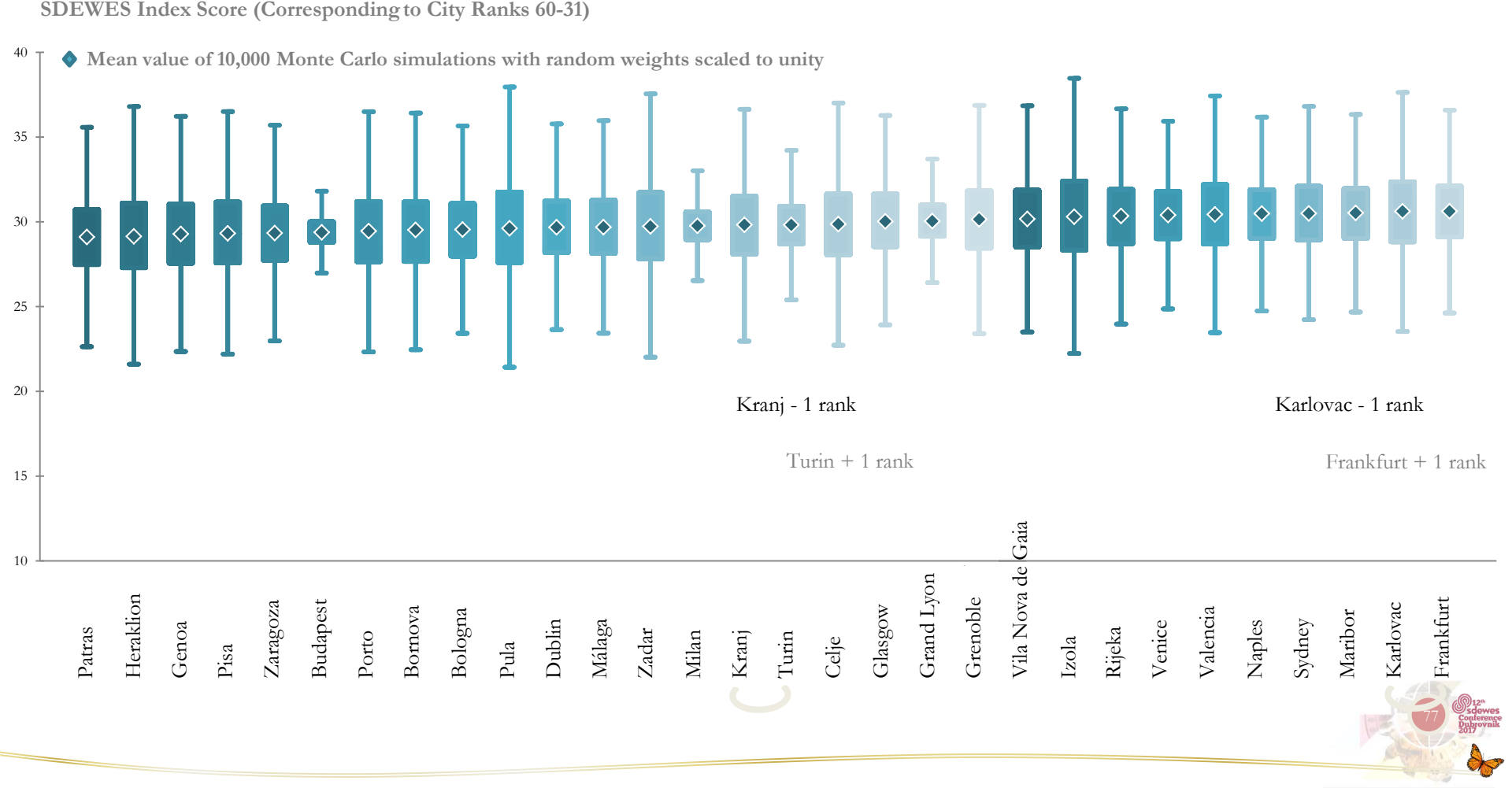
Challenges:
- D_2
- D_3
- D_6
- D_7

* With average performances in the other dimensions



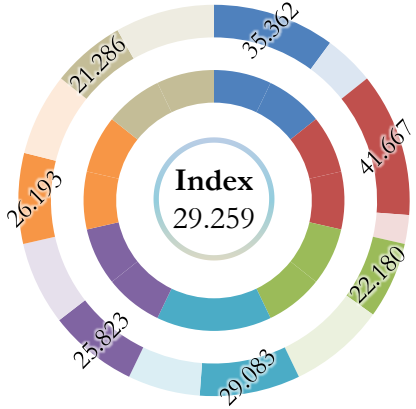
Promising Developments:
Energy Bunker for Reiherstieg District

Monte Carlo Simulations – Top 50-75% of Cities

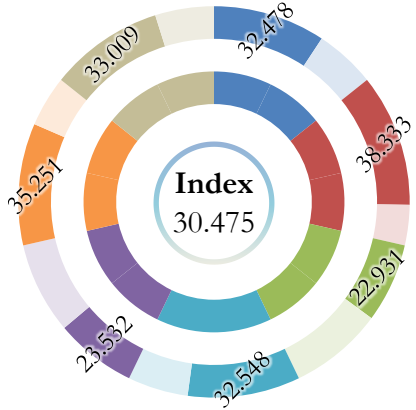


Transitioning Cities: Strenghts Turning to Opportunities

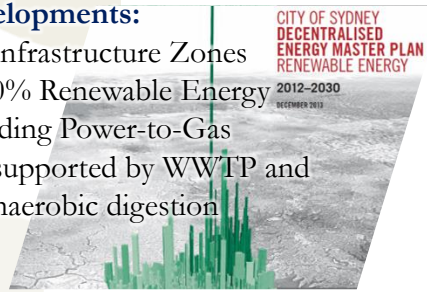
Strenghts: *
- D_1
- D_2
- D_3
- D_4
- D_6
- D_7



Strenghts: *
- D_2
- D_3
- D_4
- D_6
- D_7

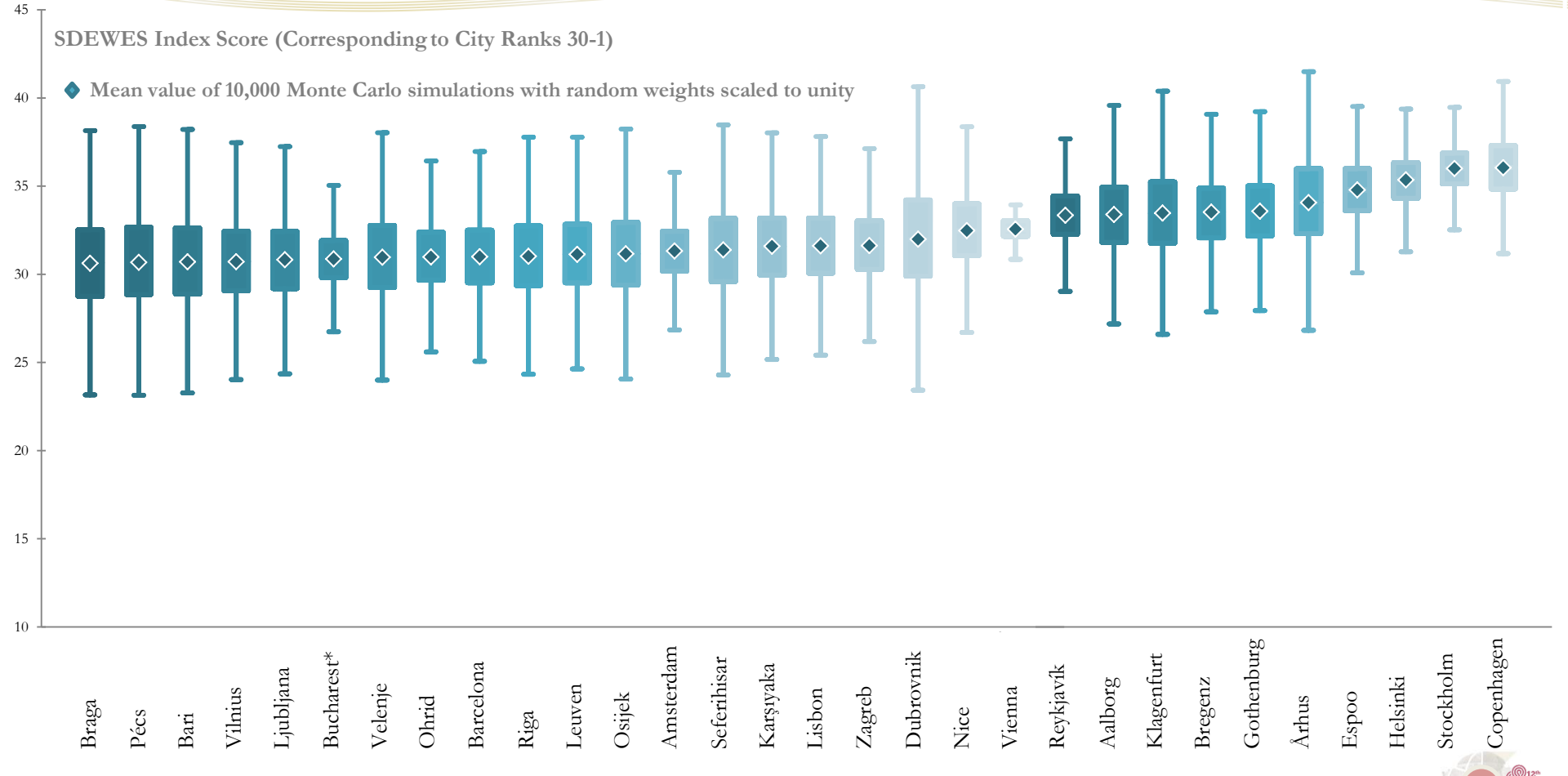


Promising Developments:
- Low Carbon Infrastructure Zones
- Integrated 100% Renewable Energy Systems, including Power-to-Gas
- Gas network supported by WWTP and dairy farms, anaerobic digestion



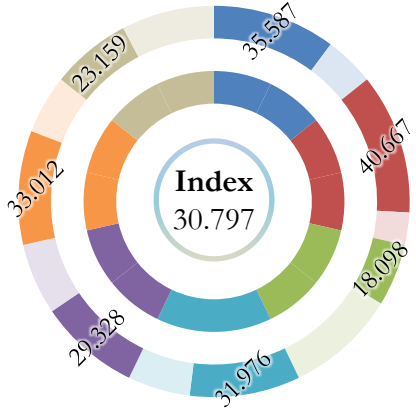
* In comparison to the average city

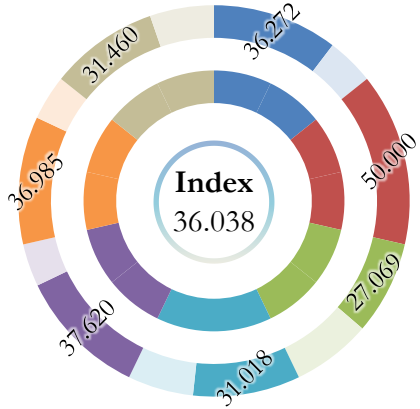
Monte Carlo Simulations – Top 25% of Cities



Pioneering Cities: Strenghts in Multiple Dimensions

Strenghts:
- D_1
- D_2
- D_4
- D_6
- D_7





Strenghts:
- D_1
- D_2
- D_3
- D_4
- D_5
- D_6
- D_7

Promising Developments:
- Ljubljana Sustainable Urban Strategy
- Ljubljana Zero Waste Strategy *

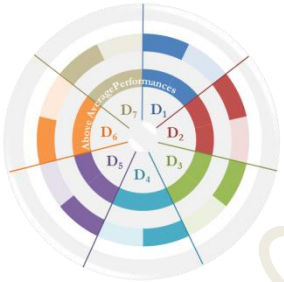
* First EU capita to adopt such a strategy

* In comparison to the average city

Beyond Ranking: City Pairings for Policy Learning

The use of the SDEWES Index for policy learning and collaboration is supported by city pairings

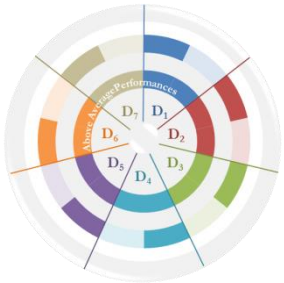
City 1



Pattern search algorithm:

Above/at or below the average city performance in the same dimension across all dimensions

City 2



20 city pairs between 2 cities

Examples of 10 such city pairs

- Pisa, Bornova
- Antalya, Sevilla
- Johannesburg, Bogotá
- Milan, Amsterdam
- Warsaw, Tallinn
- Zenica, Lviv
- Rome, Madrid
- Zagreb, Lisbon
- Skopje, Thessaloniki
- Cape Town, Athens

City 1

City 2

City *x*

13 city pairs between 3 or more cities

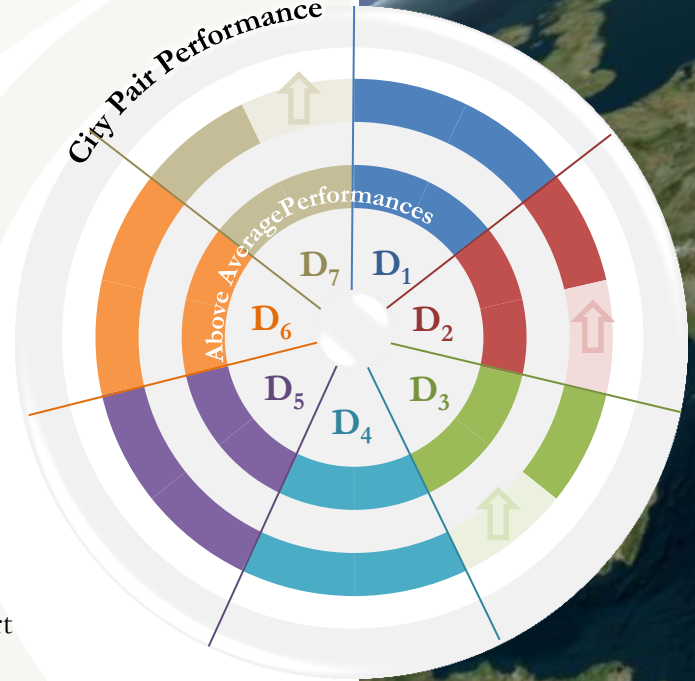
- City pairs with 3 cities: 4 pairs (12 cities)
- City pairs with 4 cities: 4 pairs (16 cities)
- City pairs with 5 cities: 3 pairs (15 cities)
- City pairs with 6 cities: 1 pair (6 cities)
- City pairs with 8 cities: 1 pair (8 cities)

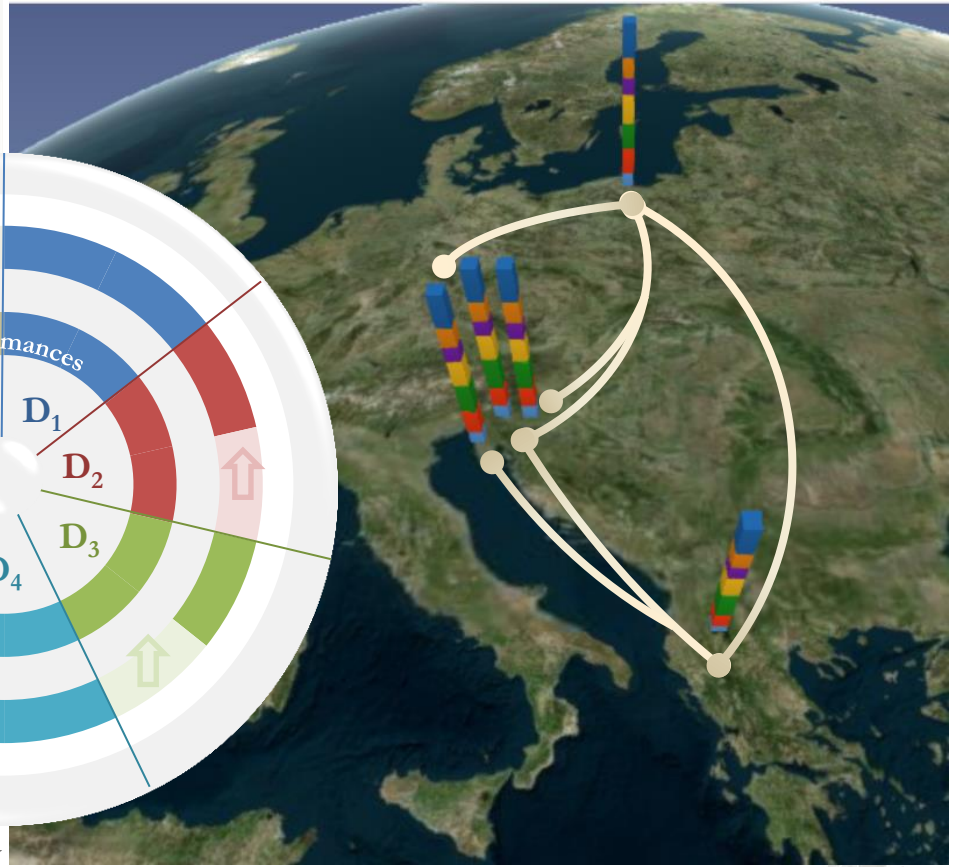
Total of 33 different pairs between 97 cities

Beyond Ranking: City Pairings for Policy Learning

Cities in the Collaboration Pair

Gdynia	28.169
Kranj	29.797
Celje	29.834
Izola	30.289
Ohrid	30.965



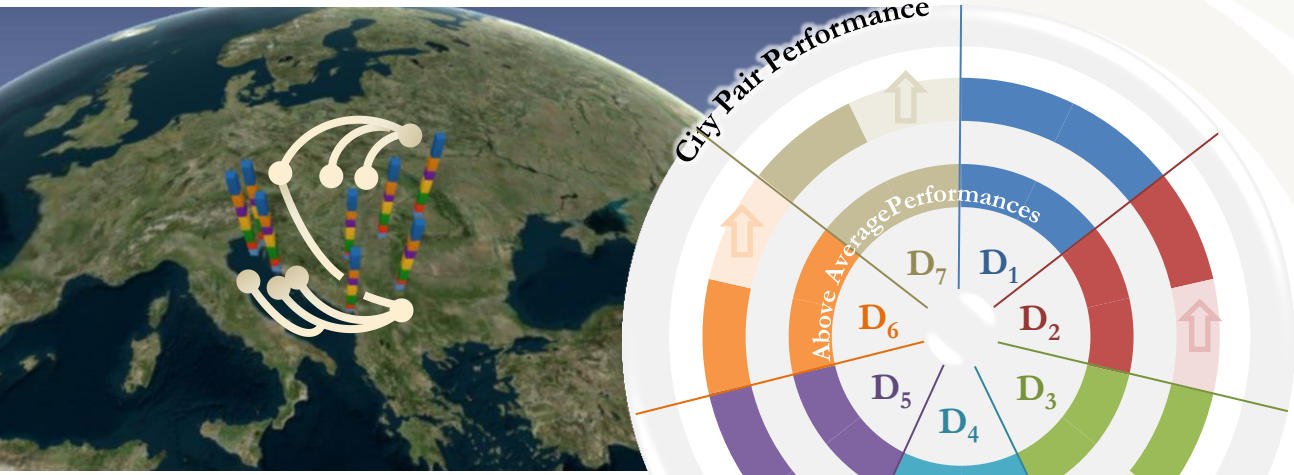


Possible areas of collaboration:

- Sea/lake based heat pumps and/or aquifer thermal energy storage to support the **penetration of renewable energy**
- Collaboration to increase R&D and innovation base for sustainability
  - Including integrated waste management

Beyond Ranking: City Pairings for Policy Learning

Collaboration to further improve near average performances, including D_2 and D_3, with additional solutions



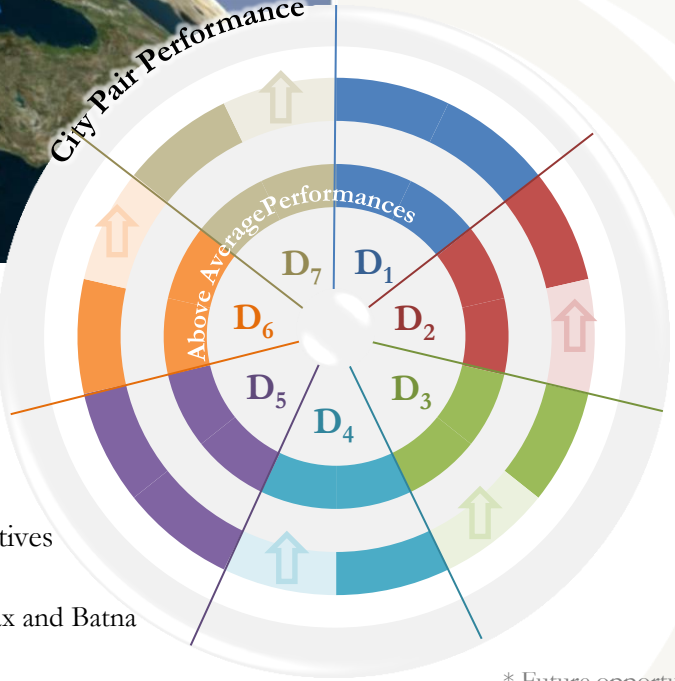
Cities in the Collaboration Pair	
Bijeljina	26.021
Podgorica	27.025
Timişoara	27.591
Niš	27.975
Cluj-Napoca	28.140
Pula	29.597
Zadar	29.709

Possible areas of collaboration:

- Utilization of residual heat from industry
  - Zadar: Food and beverage industry
  - Pula: Non-metallic minerals
  - Timişoara: Thermal power generation

Source: Stratego Project Local Maps and Heat Roadmap Europe Peta 4.2

Beyond Ranking: City Pairings for Policy Learning



Cities in the Collaboration Pair

Batna	23.722
Sfax	24.960
Bursa Nilüfer	27.432
Nitra	28.583
Kalamariá	28.593

Possible areas of collaboration:

- Implementation of renewable energy alternatives to replace high exergy heating of buildings
  - Present case in Kalamariá, Bursa Nilüfer*, Sfax and Batna
- Improvement in recycling and composting
  - Between 1 - 15 % with a need to diffuse separate collection

* Among the cities, Bursa Nilüfer is replicator city under the EU Smart Cities program

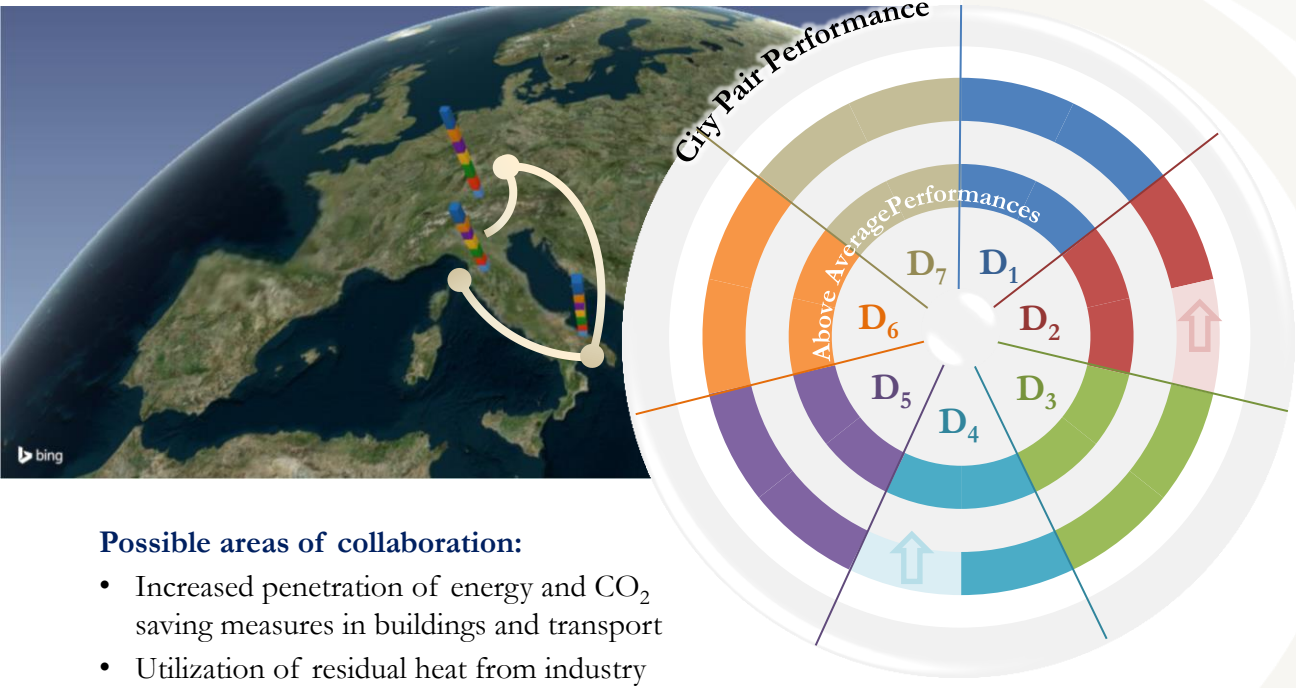
Current best practices from Nitra:

- District heating system of 20 km for 24,167 MW_t of installed capacity and 40% covered by geothermal energy
  - Supply temperature of 100°C
  - Return temperature: 50°C *

* Future opportunity: Advancement towards a low temperature network

Beyond Ranking: City Pairings for Policy Learning

Collaboration among the cities in the pairing can further improve performances in D_2 and D_4



Cities in the Collaboration Pair

Florence	28.384
Bari	30.687
Bregenz	33.494

Possible areas of collaboration:

- Increased penetration of energy and CO_2 saving measures in buildings and transport
- Utilization of residual heat from industry
  - Bari: Thermal power generation
  - Florence: WtE

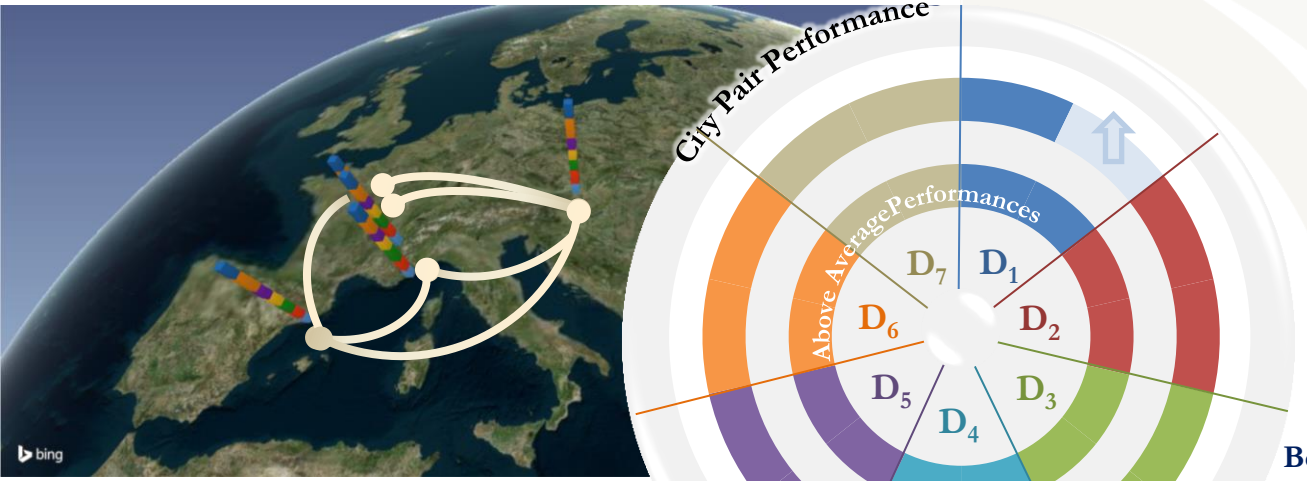
Source: Heat Roadmap Europe Peta 4.2

Best practices from Bregenz:

- Biomass district heating reduces CO_2 emission by 78 tonnes per year
  - Heating and cooling with lakewater is being planned
- Vorkloster is undertaken as a shared residential area of passive house standard

Beyond Ranking: City Pairings for Policy Learning

The utilization of residual heat and low energy districts can provide means of reducing ecological footprint



Cities in the Collaboration Pair

Grand Lyon	30.030
Grenoble	30.110
Barcelona	30.966
Nice	32.465
Vienna	32.561

Possible areas of collaboration:

- Reduction in the ecological footprint
- Utilization of residual heat from industry
  - Vienna, Nice: Waste to energy (WtE)
  - Barcelona, Grenoble, Grand Lyon: Thermal power generation (main activity), WtE, non-metallic minerals

Source: Heat Roadmap Europe Peta 4.2

Best practices from Vienna:

- Holistic refurbishment of a low energy district for 2444 MWh/yr primary energy savings and 550 tCO_2/yr emissions reduction

  Source: EU Smart Cities Information System (SCIS)
- Net-zero buildings with –5 kWhPE/m^2-y performance based on PV plus server heat

Beyond Ranking: City Pairings for Policy Learning

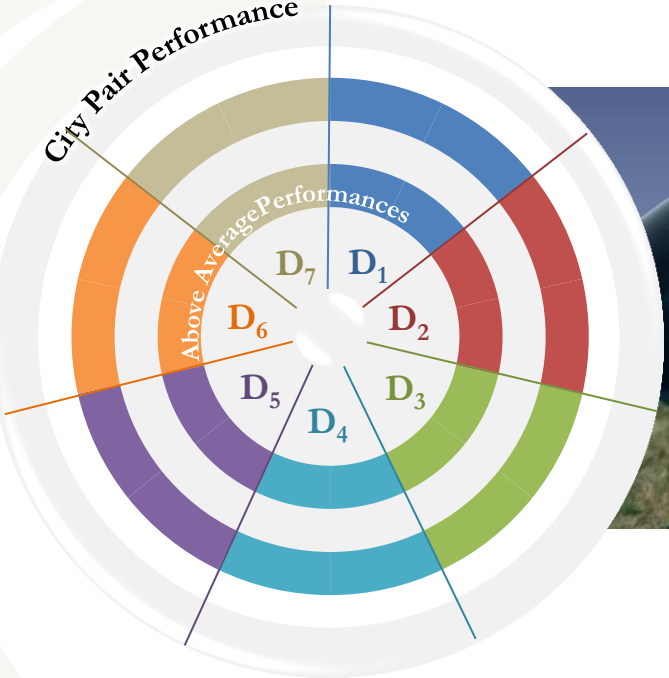
The city pair has above average performances in all dimensions

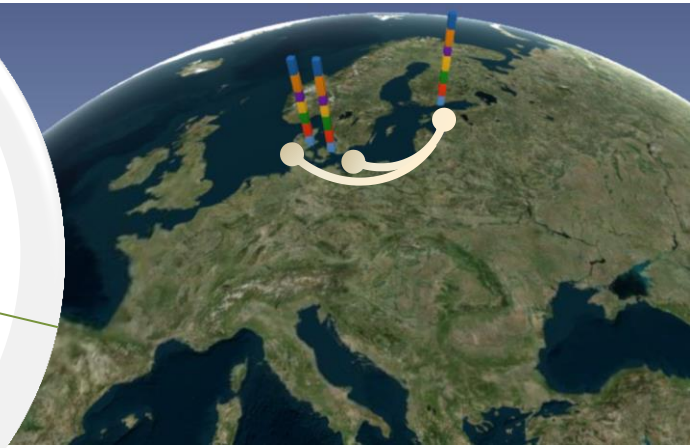
Best practices from the city pair:

- Copenhagen: DH coverage is 98%; excess wind will be integrated towards **4GDH**
- Helsinki: CHP based district heating network with thermal energy storage (TES)

Low temperature district heating:

- Copenhagen: : Renovations of the suburbs of the city at Albertslund and Høje Taastrup
  - Heat loss is reduced from 40% to 13% with 555 MWh annual energy savings
    Source: Danish Energy Agency
- Århus: Demonstration of low temperature district heating in a satellite town (Lystrup)
  - Supply temperatures between 65°C and 85°C
  - Additional development: PV-Thermal (PV-T) in buildings





Cities in the Collaboration Pair

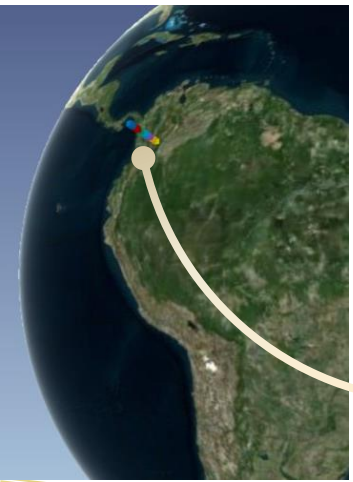
Århus	34.049
Helsinki	35.348
Copenhagen	36.038

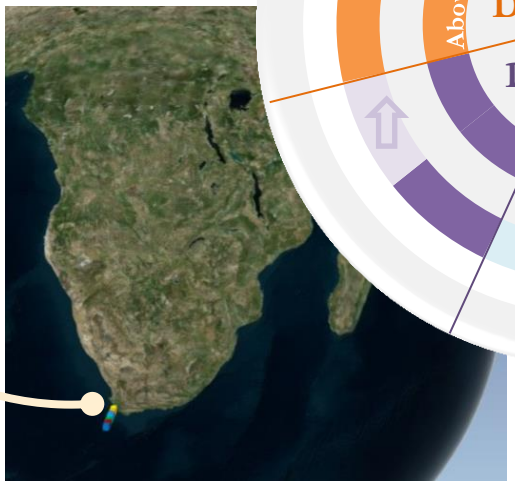
Beyond Ranking: City Pairings for Policy Learning

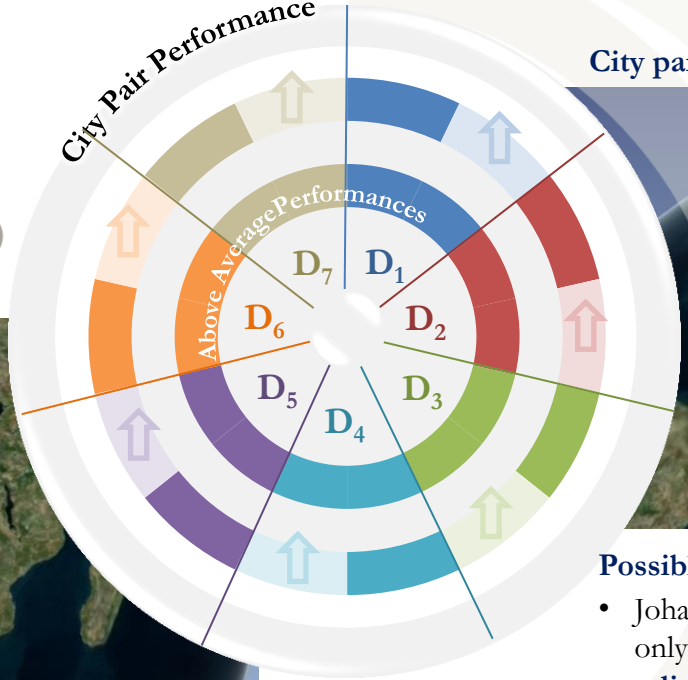
Transfer of knowledge and experiences from pioneering to challenged cities can also trigger opportunities

Cities in the Collaboration Pair

Johannesburg	17.479
Bogotá	22.112







City pairs with opposite performances:

Possible areas of collaboration:

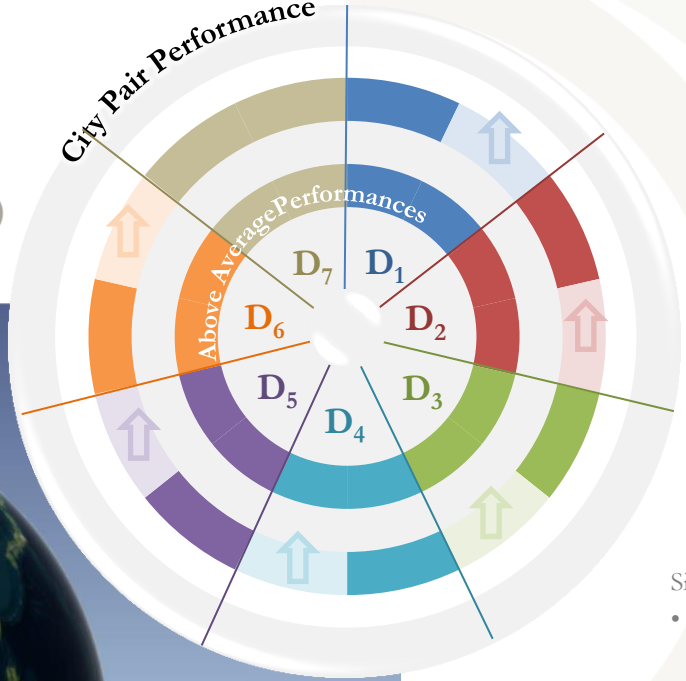
- Johanneburg: Combined heat and power is only used in certain data centers with **reliance on coal based power generation**
- Bogotá: Potential for solar and waste-to-energy, e.g., banana and coffee pulp waste

Beyond Ranking: City Pairings for Policy Learning

The only strength in R&D and innovation can also be transformed into an opportunity for sustainability

Cities in the Collaboration Pair

Tianjin	15.277
Istanbul	20.544
Bangalore	22.839



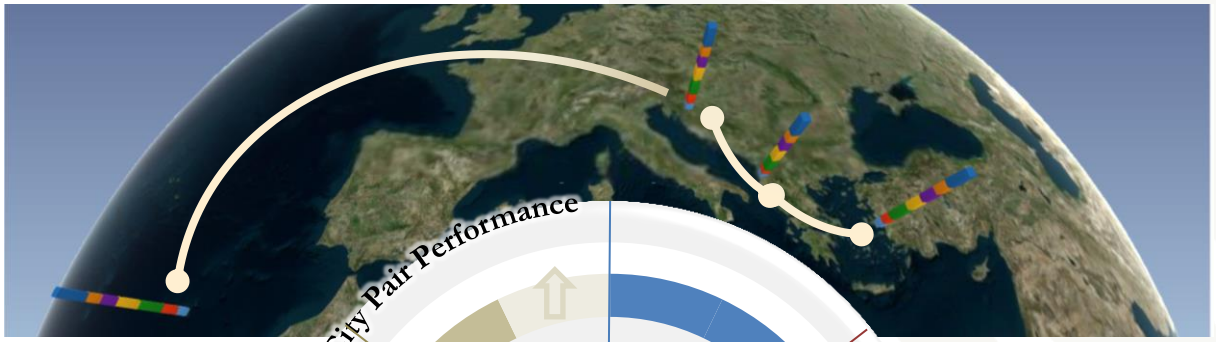
Commonalities within the city pair:

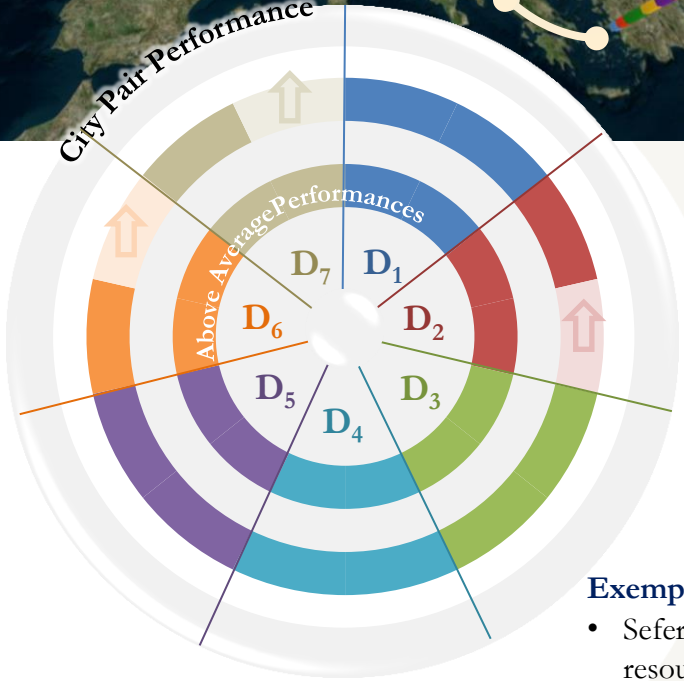
- Opportunities to utilize local experiences for an urban energy system transition
- The **airport energy system** is more advanced than the urban energy system
  - Bangalore: 7.5 MW / 16 MW of the energy needs from on-site solar PV *
  - Istanbul: Natural gas driven trigeneration
- Tianjin Sino-Singapore Eco-City Passive House that uses 90% less energy

Similar best practice: Helsinki *

- Largest airport solar power plant in the Nordic countries (500 kWp)

Beyond Ranking: City Pairings for Policy Learning





Cities in the Collaboration Pair

Tirana	27.326
Funchal	28.976
Karlovac	30.591
Seferihisar	31.344

Certain strenghts:

- High share of renewable energy in electricity generation
  - Tirana: 100%
  - Karlovac: 74%

Certain weaknesses:

- Funchal: Thermoelectric plants based on fuel oil/natural gas dominate the energy system of Madeira Island

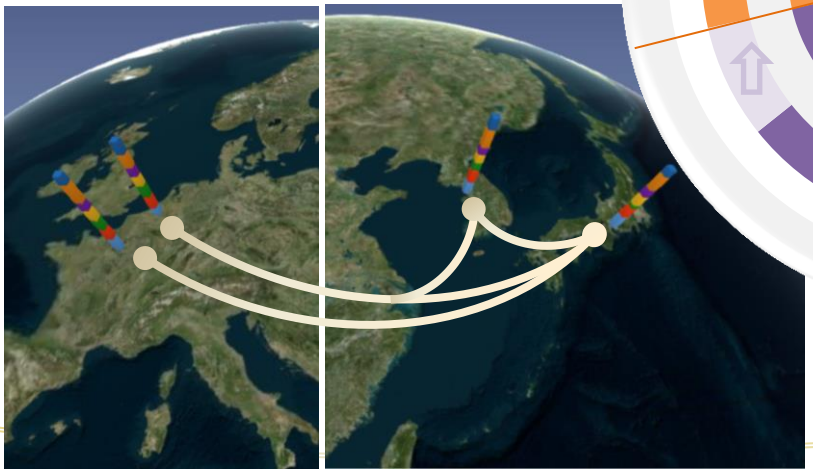
Exemplary opportunity:

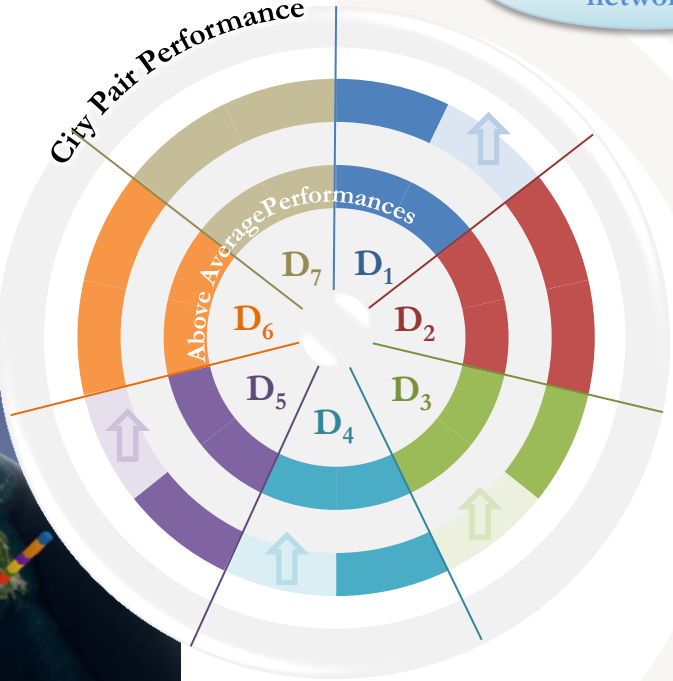
- Seferihisar: Utilization of geothermal resources for electricity production, greenhouse heating and tourism *

* CO_2 capture/utilization is important: Both Na/Ca–HCO_3 and Na–Cl thermal waters

Beyond Ranking: City Pairings for Policy Learning

Cities in the Collaboration Pair	
Nagoya	20.999
Incheon	25.388
Antwerp	27.739
Paris	28.283





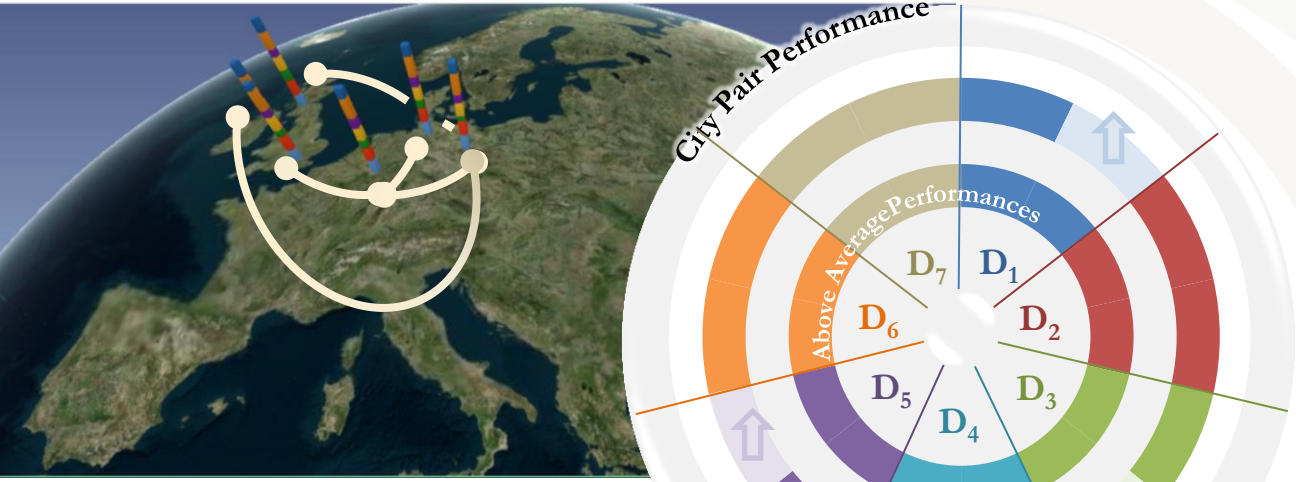
District cooling networks

Possible areas of collaboration:

- Increased penetration of locally sourced **renewable energy in district networks**
  - Incheon: Natural gas driven CHP DHC with biogas power plant
  - Nagoya: DHC in certain districts
  - Paris: 71 km district cooling network expansion achieved by utilizing the existing sewage system network
    - District heating network with 53% renewable or recovered energy share (12% bioenergy, 1% geothermal, 40% waste)

Beyond Ranking: City Pairings for Policy Learning

The realization of a smart city requires smart energy, smart energy behaviour and smart re-use of resources



Cities in the Collaboration Pair	
London	25.477
Berlin	25.572
Cologne	26.649
Hamburg	27.243
Birmingham	28.810
Glasgow	30.012

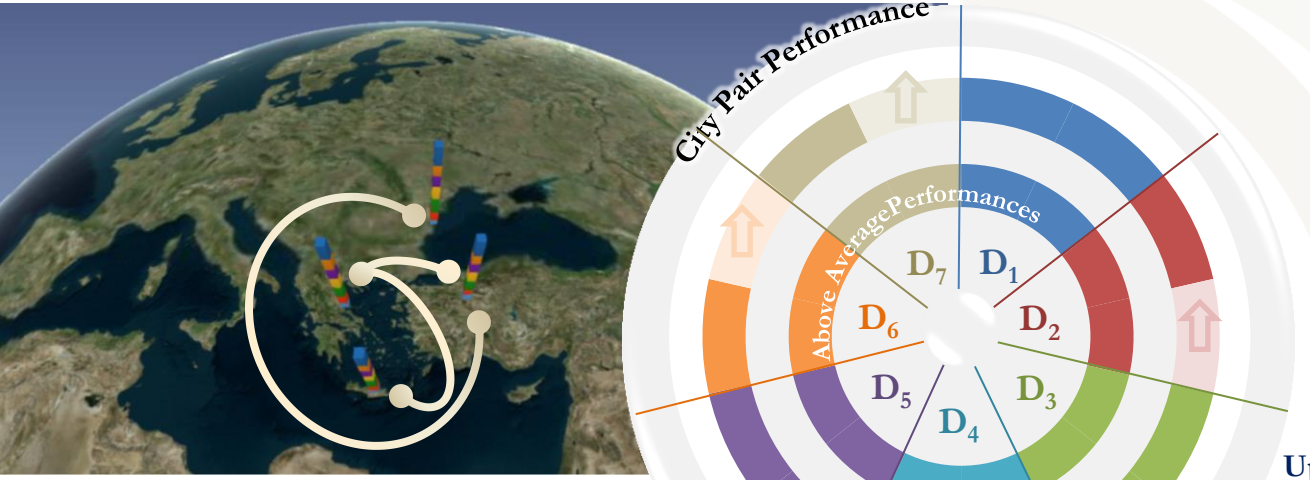
Possible areas of collaboration:

- De-carbonization of the existing CHP based district heating networks
  - Glasgow: Utilization of renewable energy supported by new behavioural habits within a smart grid scheme
  - Hamburg: Reiherstieg district as an example of displacing the use of coal
- Cologne: Support of the CHP based district heating based on **demand side management, energy storage, heat pump and power-to-gas**

Source: Stadler, I., (2015) Why Cities will have the Key Role in 100% Renewable Power Systems, SDEWES Plenary Lecture

Beyond Ranking: City Pairings for Policy Learning

Pilot low energy renewable energy buildings and districts are among important areas for collaboration



Cities in the Collaboration Pair	
Eskişehir Tepebaşı	27.105
Volos	28.536
Constanţa	28.674
Heraklion	29.127

Possible areas of collaboration:

- Pilot low energy buildings and districts with high shares of renewable energy utilization
- Continued improvements in air quality
  - Heraklion: 23.00
  - Eskişehir Tepebaşı: 31.6
  - Volos: 32.49
  - Constanţa 36.9

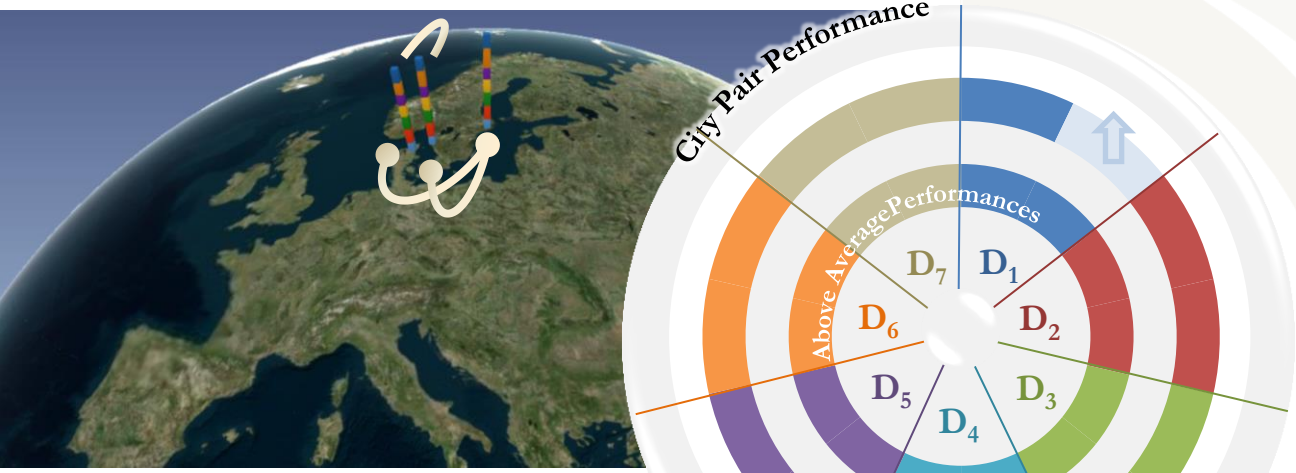
WHO Guideline for annual mean PM10: 20 µg/m^3

Upcoming developments contributing to future improvement in the value of D_2:

- Eskişehir Tepebaşı: Building renovation for near-passive buildings (completion 2019)
  - PV/BIPV, heat pumps, biomass
  - Low energy LED lighting
- Constanţa: Cogeneration with biogas from the sludge of wastewater treatment

Beyond Ranking: City Pairings for Policy Learning

Shared economy concepts such as "Open District Heating" is applicable to cities beyond Stockholm



Possible areas of collaboration:

- Open District Heating towards achieving resource-neutral networks involving 100% renewable or recycled fuels

Cities in the Collaboration Pair

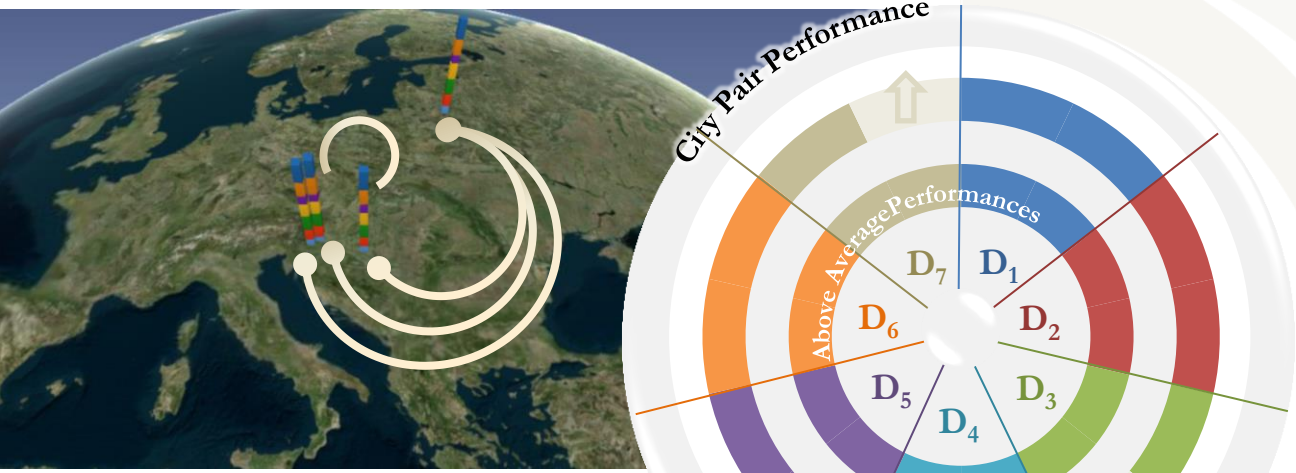
Aalborg	33.378
Gothenburg	33.572
Stockholm	36.007

Best practices from Stockholm:

- Increase in connections to an Open District Heating network, including data centers
- New biofuel-fired CHP 8 plant towards phasing-out the use of coal by 2020
- 90% fossil fuel independent city fleet
- Biogas procurement for waste trucks
- Pilot facility for biochar based on hydrothermal carbonisation process

Beyond Ranking: City Pairings for Policy Learning

Increased CO_2 targets supported by R&D



Cities in the Collaboration Pair

Maribor	30.496
Pécs	30.655
Vilnius	30.704
Velenje	30.947

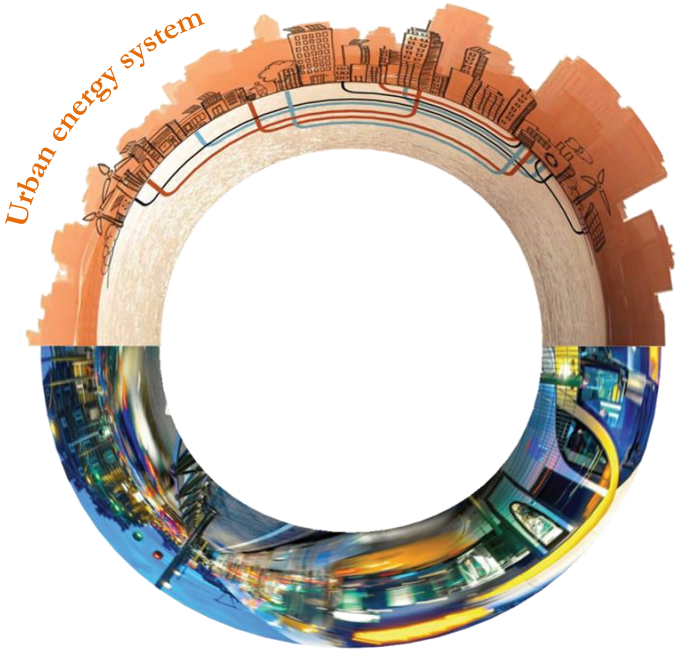
Renewable energy transition progress:

- Maribor: Existing district heating is transformed as a CHP based network, with plans for including solar energy
- Pécs: 70 MW_t and 35 MW_e from biomass
- Vilnius: The city heat facilities will be modernized, including energy from wastewater and increased biomass

Transition to renewable energy systems

What If the Future of Cities were SDEWES Aware?

Use **energy** resources rationally at the right amount, quality, and time



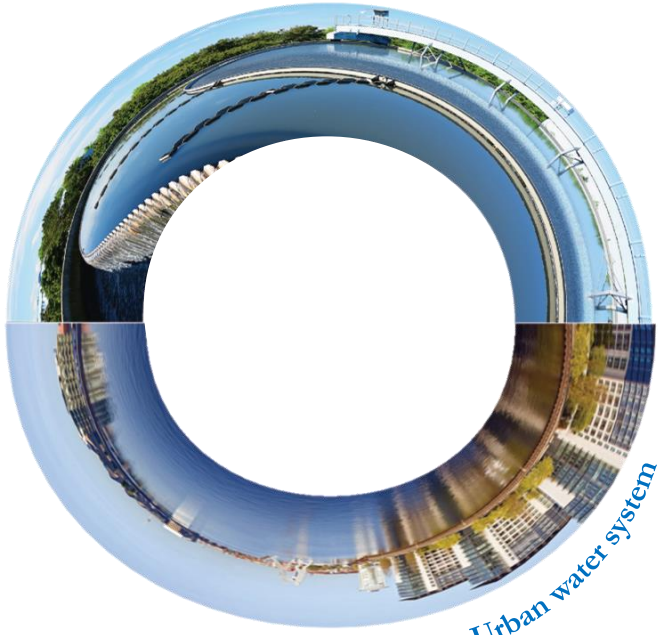
Linking the Systems – Energy

towards 100% renewable energy

What If the Future of Cities were SDEWES Aware?

Linking the Systems – Water

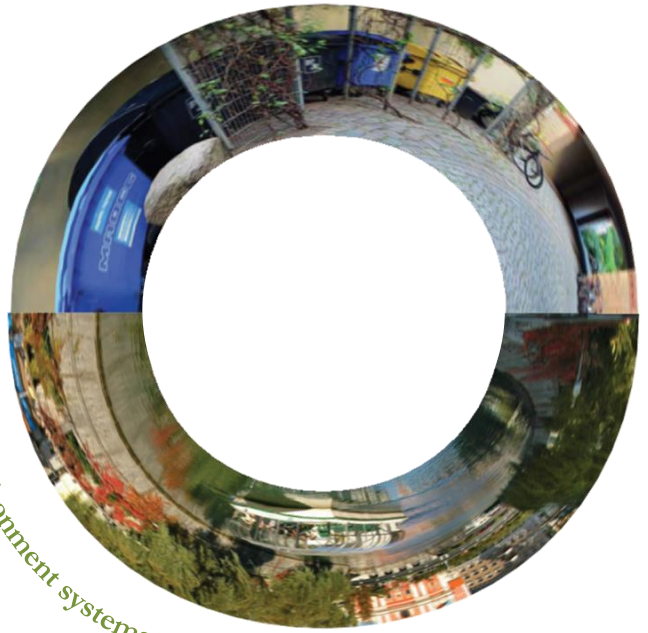
Act to preserve
water resources



Urban water system

What If the Future of Cities were SDEWES Aware?

Linking the Systems – Environment



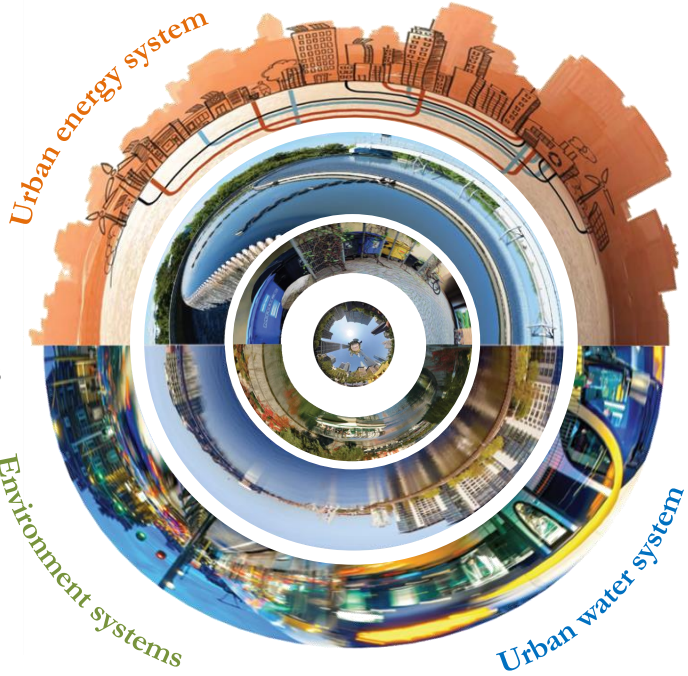
Environment systems

And seek integration whenever possible to valorize limited natural resources in better respect of **environmental** balances

SDEWES Aware City – Linking the Systems

Use **energy** resources rationally at the right amount, quality, and time

Act to preserve **water** resources



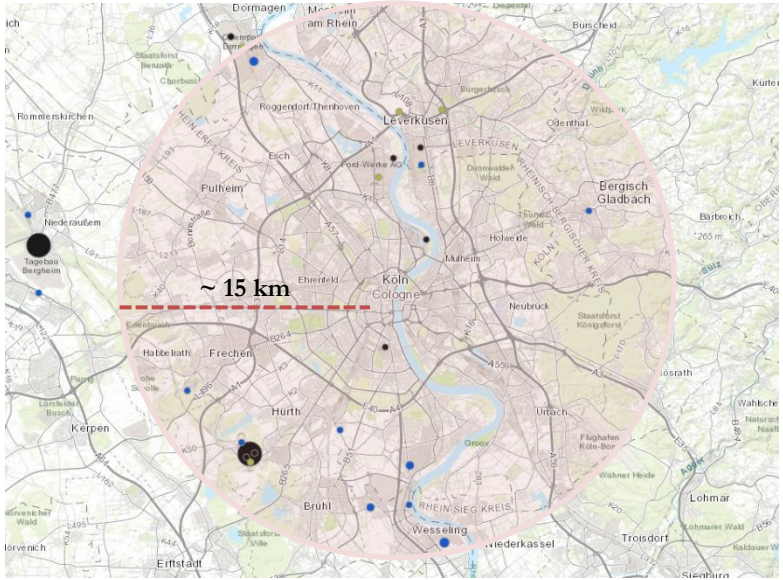
And seek integration whenever possible to valorize limited natural resources in better respect of **environmental** balances

Possible Scenario: Utilization of Residual Energy

1) Utilization of residual energy and biowaste in the urban context and vicinity with additional energy savings

- Including data from Heat Roadmap Europe Pan-European Thermal Atlas (Peta) 4.2

Total theoretical excess heat annually
(Based on European Pollutant Release and Transfer Register)

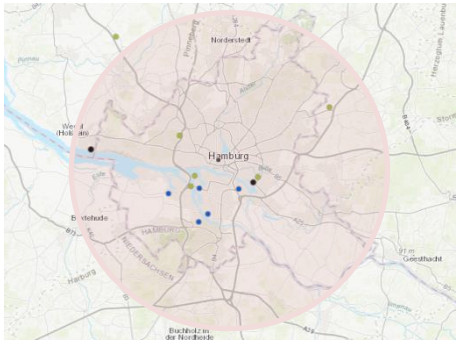


Cologne

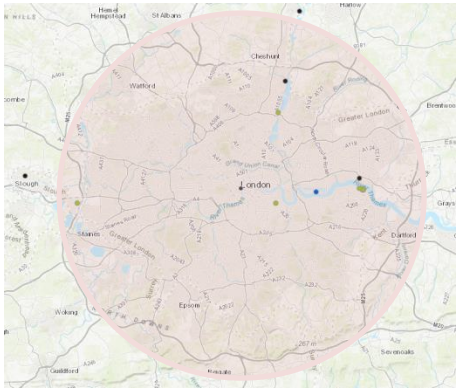
Excess heat in 5 main categories:

- Thermal power generation
- Mining and quarrying
- Chemical and petrochemical
- Fuel supply and refineries
- Paper, pulp and printing

Maximum available amount:
~38.9 TWh/year
(High temperature residual heat)



Hamburg: **~ 10.9 TWh/year**

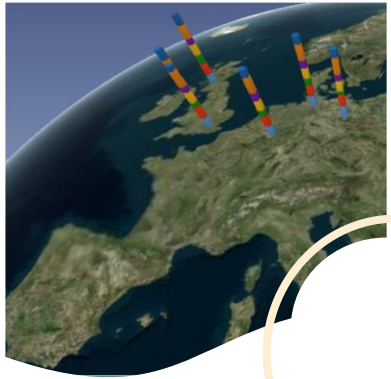


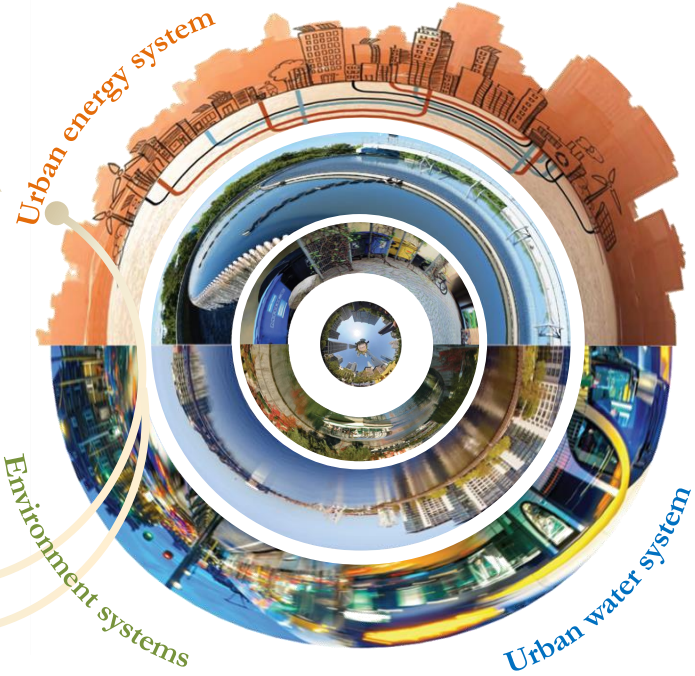
London: **~ 6.4 TWh/year**

Source: Pan-European Thermal Atlas (Peta) 4.2 <http://www.heatroadmap.eu/peta.php>

Possible Scenario: Utilization of Residual Energy

Cities in the Collaboration Pair	
London	24.456
Berlin	25.572
Cologne	26.649
Hamburg	27.243
Birmingham	28.810
Glasgow	30.012





Scenario Definition

- **Utilization of residual** heat within ~15 km based on a scenario multiplier
  - Median available excess heat for cities in the sample: 1.61 TWh
  - 10% (above median) or 15% (below median) of maximum theoretical excess heat for each main industrial category
- Utilization of 20% of the available **biowaste/ urban biomass** in the transport sector as bioenergy based electricity, gas or liquid fuel
- **End-use savings** in buildings and transport in a matching amount *
  - Average 12% savings in building and 10% in transport

* 50% of the residual energy in Cologne corresponds to more than 75% of the total building energy usage so that the end-use savings are limited to 40%. Birmingham and Glasgow have limited opportunities within a ~15 km radius

Direct Scenario Benefits Include:

- Savings in energy per capita
- Final to primary energy ratio improvement

Possible Scenario: Utilization of Residual Energy

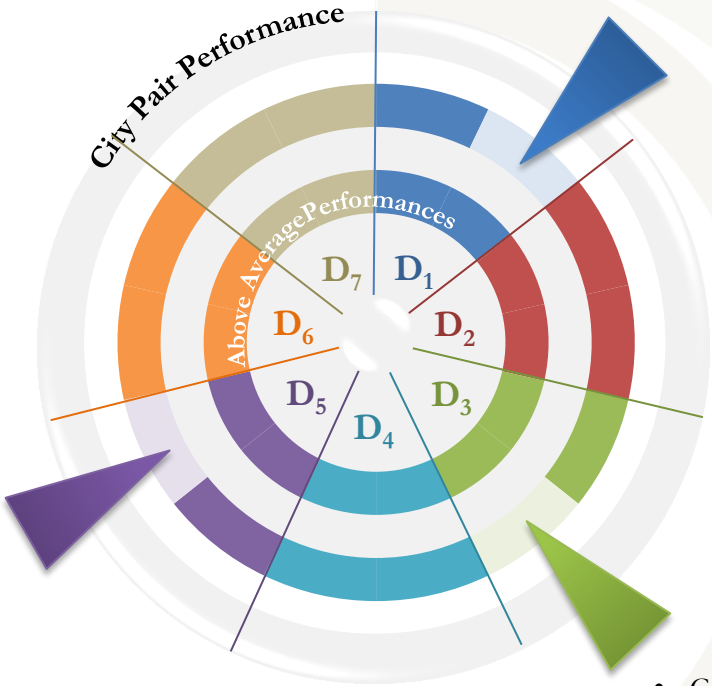
Cities in the Collaboration Pair	
London	24.456
Berlin	25.572
Cologne	26.649
Hamburg	27.243
Birmingham	28.810
Glasgow	30.012

Average advancement in rank in the city collaboration pair: 10

* Excluding additional co-benefits

Performance of Cologne in D_5 :

Before Scenario	*After Scenario*
19.043	23.548



Performance of Cologne in D_1:

Before Scenario	*After Scenario*
21.375	28.949

Index performance of Cologne:

Before Scenario	*After Scenario*
Rank: 93	Rank: 55

Cologne advances to the next quartile (Q_3)

Additional opportunities:

- Continued increase in the utilization of renewable energy potential

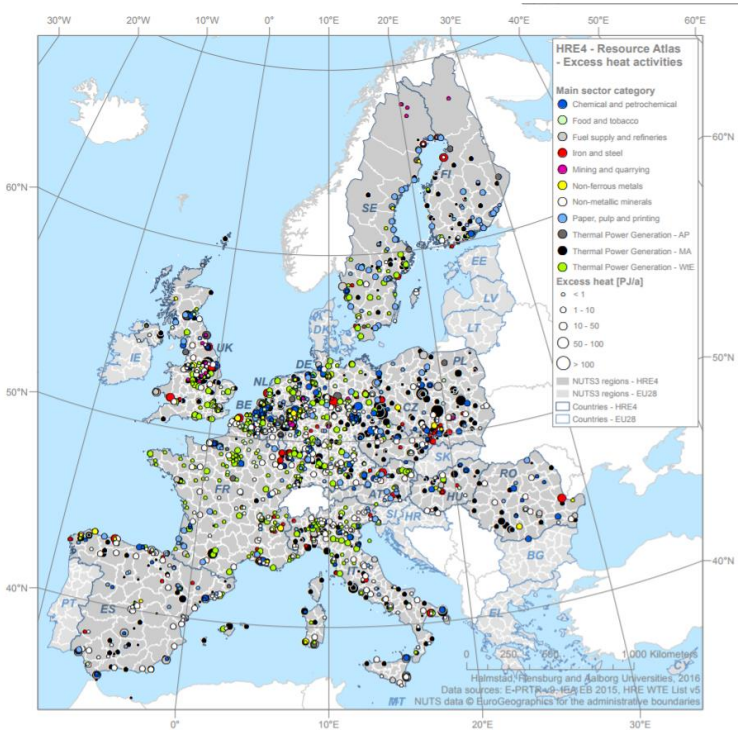
Possible Scenario: Utilization of Residual Energy

Scenario Definition

- **Utilization of residual heat** within ~15 km based on a scenario multiplier
  - 30% of maximum theoretical excess heat from all categories
- Utilization of 20% of the **available biowaste/ urban biomass** in the transport sector as bioenergy based electricity, gas or liquid fuel
- **End-use savings** in buildings and transport in a matching amount *
  - Average 15% savings in buildings and 13% savings in transport
- Utilization of the **residual heat in wastewater** with a multiplier of 0.80 **

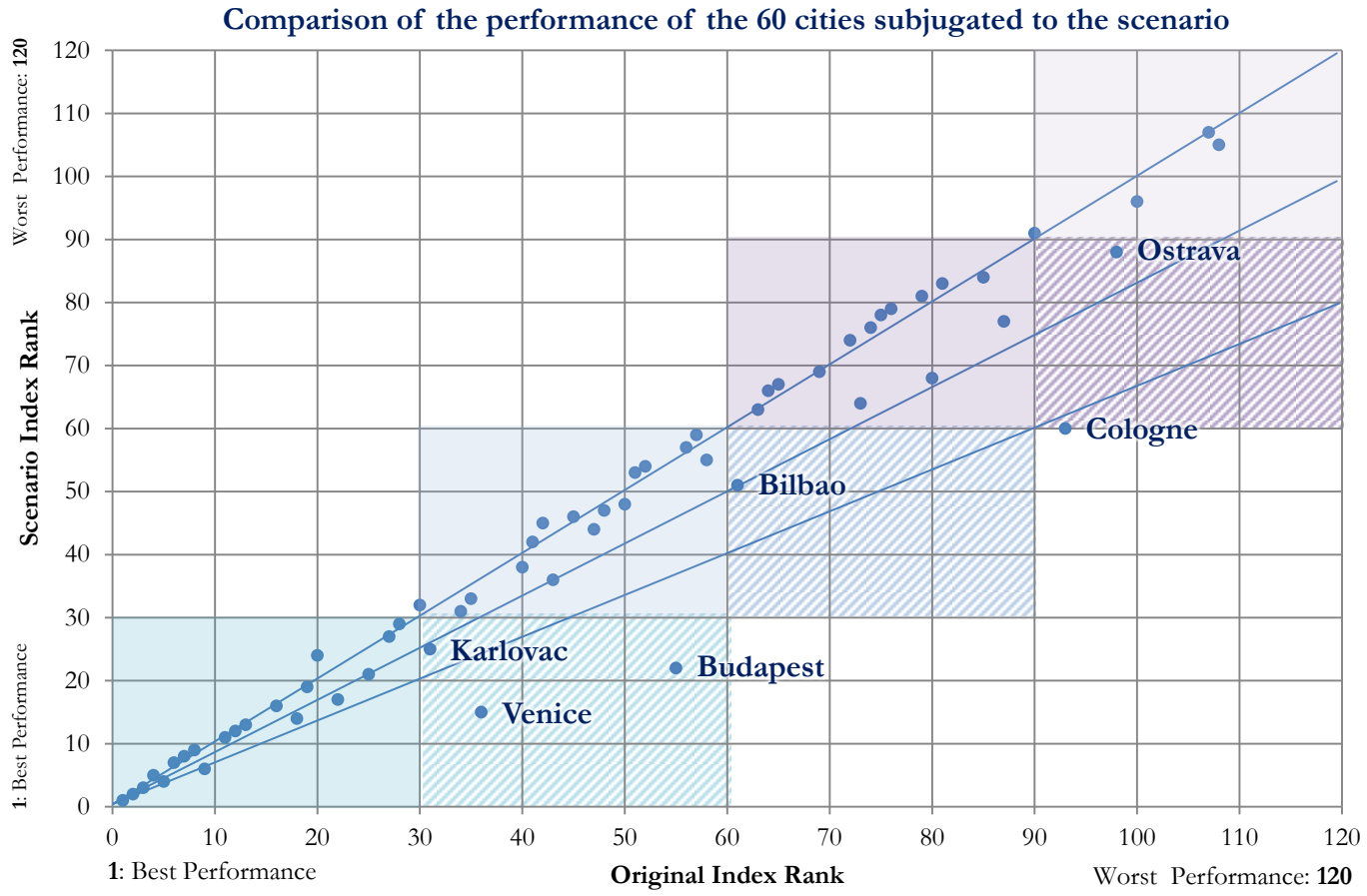
* Budapest, Cologne, Ostrava, Venice (including Mestre for consistency with the scope of SEAP) are outliers limited to 40%
* Cities with local maps based on the Stratego Project

Correspondence of 60 cities with the SDEWES Sample



Source: Heat Roadmap Europe Excess Heat Atlas

Possible Scenario: Utilization of Residual Energy



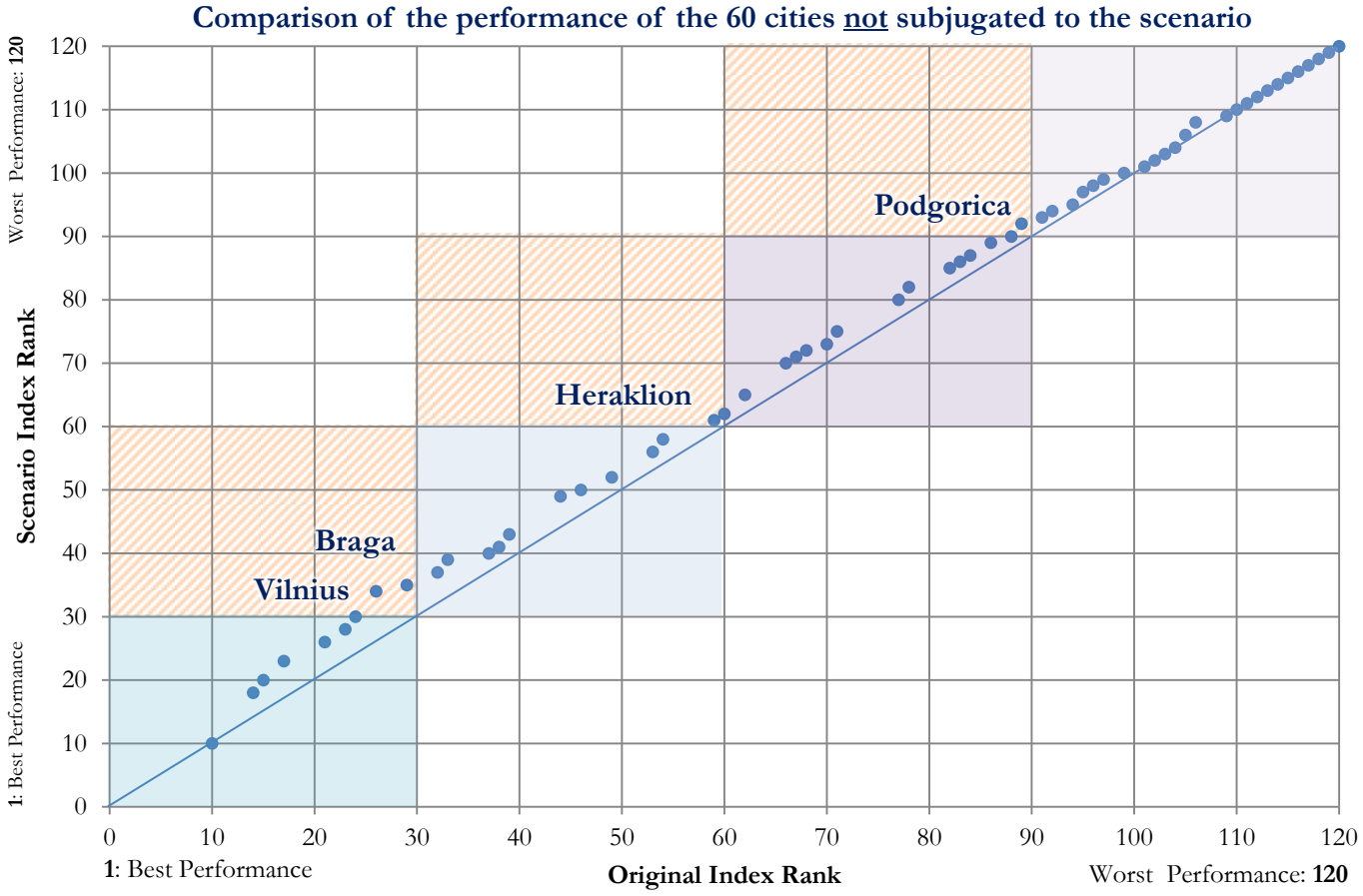
Legend

Change in rank in the same quartile

Top 25% | Top 25%
Top 50% | Top 50%
Lower 50% | Lower 50%
Lower 25%

Advancement in rank to the next quartile

Possible Scenario: Utilization of Residual Energy



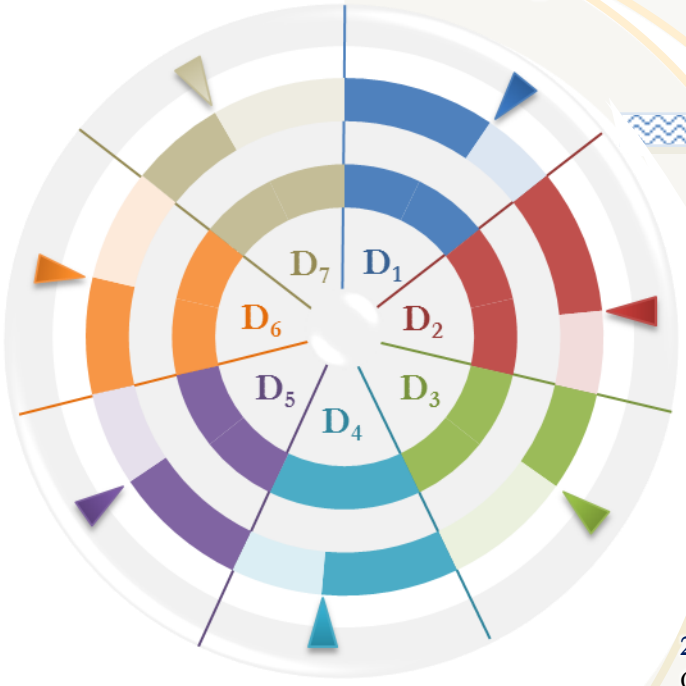
Legend

- Top 25%
- Top 50%
- Lower 50%
- Lower 25%

Retreat in rank to the previous quartile

Foresight for Dynamic Average City Performance

Foresight of Trends with an Impact on the Evolution of Average City Performance



2035:
The electricity sector reaches carbon neutrality

2030:
- Increases in energy efficiency alone reduces emissions by 40-50%
- Mass-transit utilization in cities doubles and ICE are phased-out

2025:
Emissions from deforestation and land-use changes are cut to zero

2040:
Renewables obtain a 100% share in primary energy usage given a doubling every 5.4 years

2050:
The world reaches net-zero CO_2 emissions

2020: Year by which cities need to "bend the curve"
Cities upgrade at least 3% of their building stock to zero or near-zero emissions each year

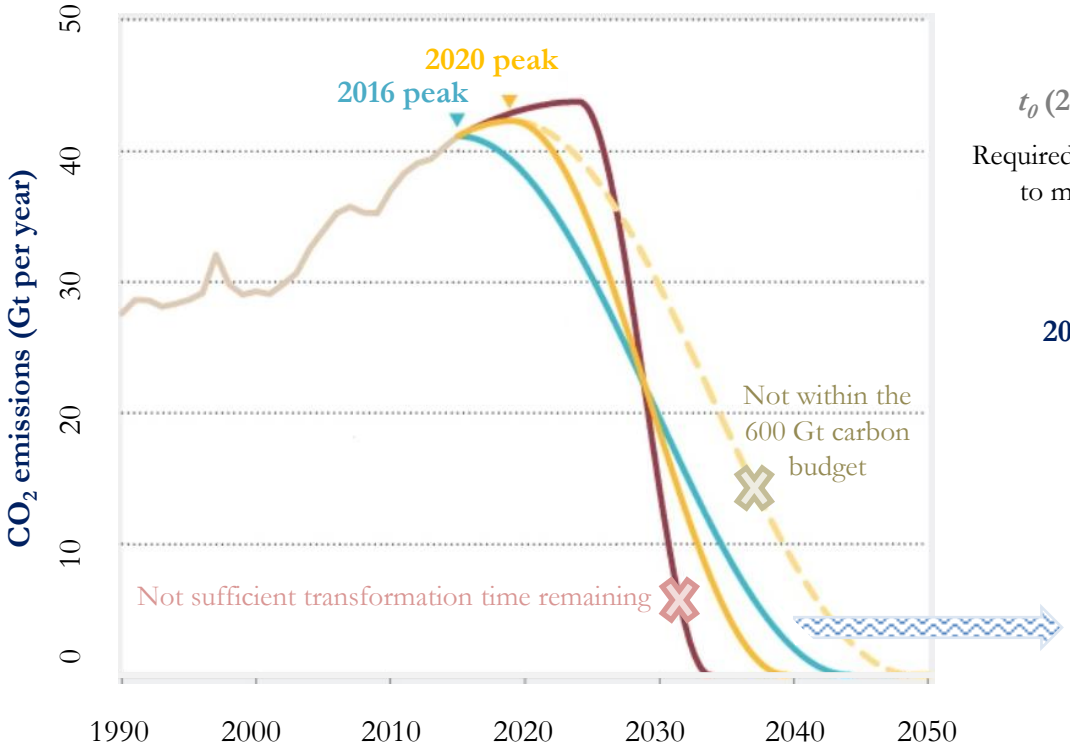
Present Average City Performance (2017)*

2020 — 2025 — 2030 — 2035 — 2040 — 2050

* Data represents most recent year; 2017 SEAP Monitoring Reports provide 2015 values

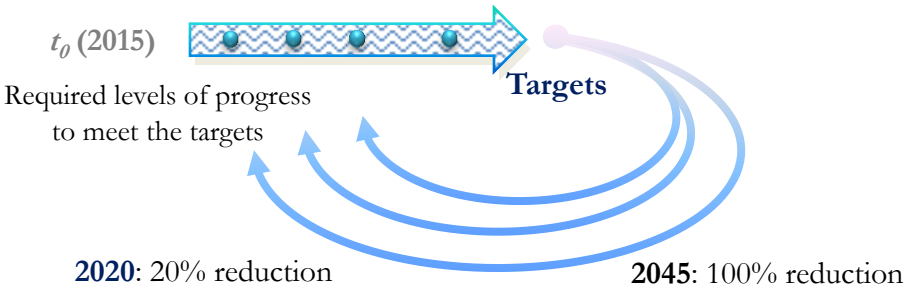
Sources:
Figueres, C. et al. (2017), Three years to safeguard our climate, *Nature* Vol. 546, pp. 593–595.
Rockström, B. J. et al. (2017), A roadmap for rapid decarbonization, *Science* Vol. 355 (6331), pp. 1269–1271.

Foresight for Dynamic Average City Performance

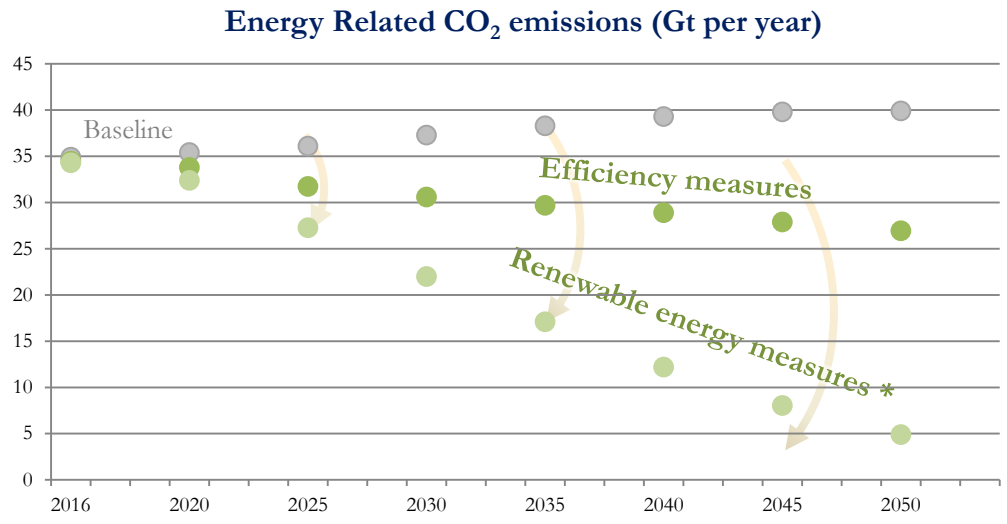


Source:
Stefan Rahmstorf/Global Carbon Project
<http://go.nature.com/2RCPCRU>

Backcasting Scenarios for the Average City Performance based on Necessary Targets

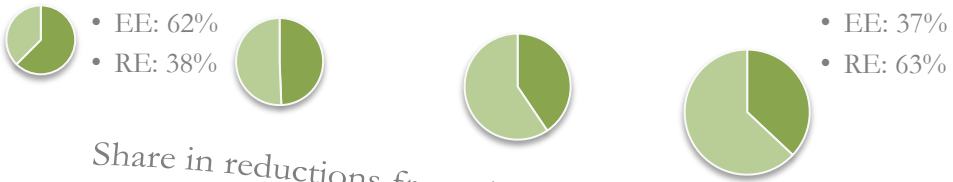


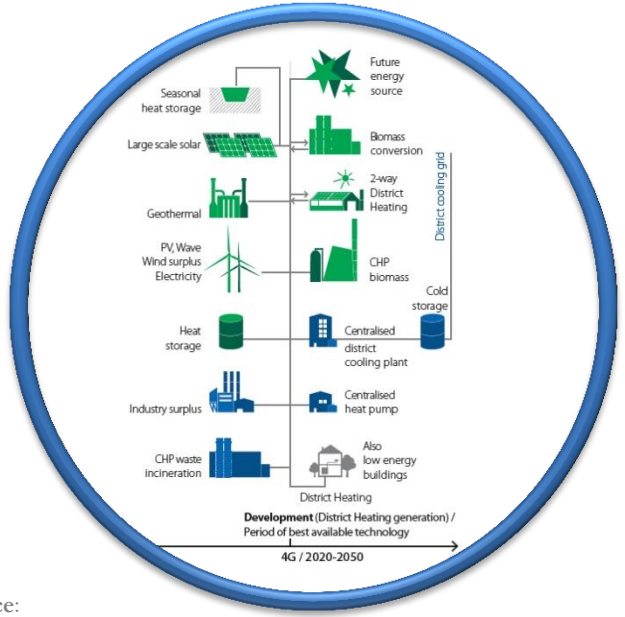
Foresight for Dynamic Average City Performance



Adapted from IEA Energy Technology Perspectives 2017 "Beyond 2 Degree Scenario (B2DS)"

* Including all decarbonization options





Source:
Lund, H. et. al. (2014) 4th Generation District Heating, *Energy* Vol. 68, 1-11.

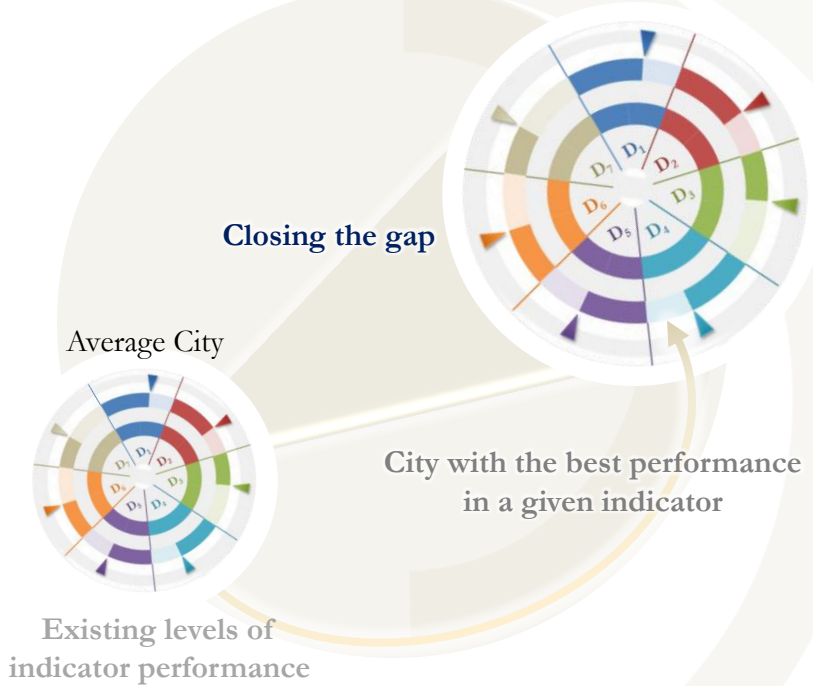
Annual efficiency contributions to CO_2 reduction targets:

2030 CO_2 target:
- At least ~2.0% p.a.

2045 CO_2 target:
- At least ~1.5 % p.a.

Closing the Gap with the Best Indicator Performances

Scenario: The average city catches the performance of the best performing city per indicator of the SDEWES Index by target years



Examples:

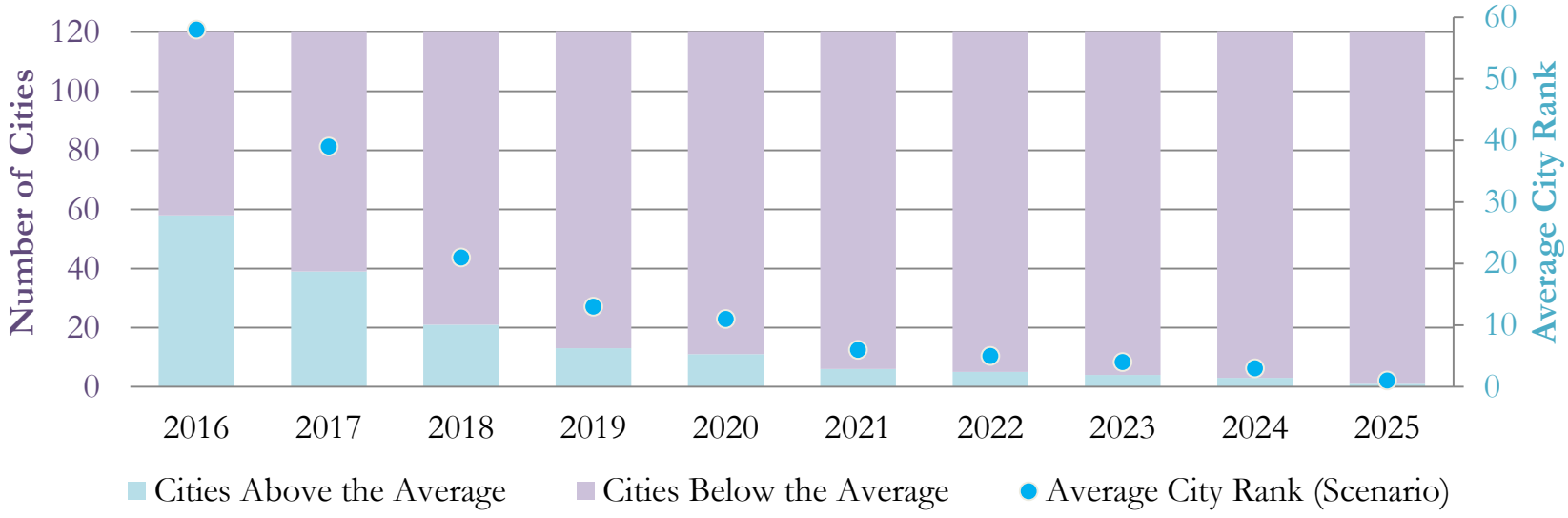
Indicator (Unit)	Value	City/Cities	Target Year
Renewable energy share in electricity (%)	100	Reykjavík	2035
Green energy in transport (%)	12.04	Rio de Janeiro, Stockholm	2025
Water consumption per capita (m^3/year)	3.1	Amsterdam	2050
Water quality index (/100)	99	Helsinki, Christchurch	2035
Annual mean PM_{10} concentration ($\mu g/m^3$)	12.0	Braga	2040
Waste and wastewater management	6.5	Bregenz	2025
Compact urban form and green spaces	3.0	Ohrid	2030
Inequality adjusted well-being	8.2	Reykjavík	2030
Tertiary education rate (%)	62.4	Incheon	2050
R&D and innovation policy orientation	3.0	Berlin	2025

In addition to the examples given above, all indicators are subjugated to incremental improvements in the scenarios except the indicators for the average number of industries and renewable energy potential .

Closing the Gap with the Best Indicator Performances

Main Advantage of the Scenario:

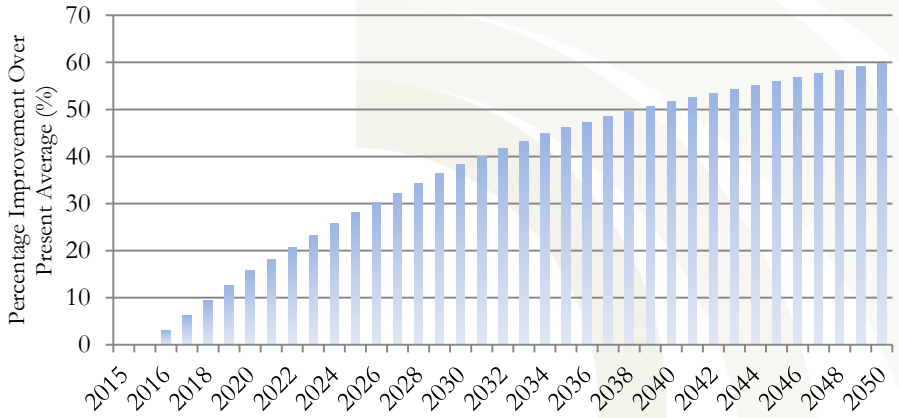
Rapid Improvement in All Indicators Simultaneously to Reach the Best Level of Performance by the Target Year



Present-day city closest to the rank of the average scenario city:

Genoa	Riga	Vienna	Århus	Helsinki
Vila Nova de Gaia	Dubrovnik	Gothenburg	Espoo	Copenhagen

2030 Sustainable Development Goals and Beyond

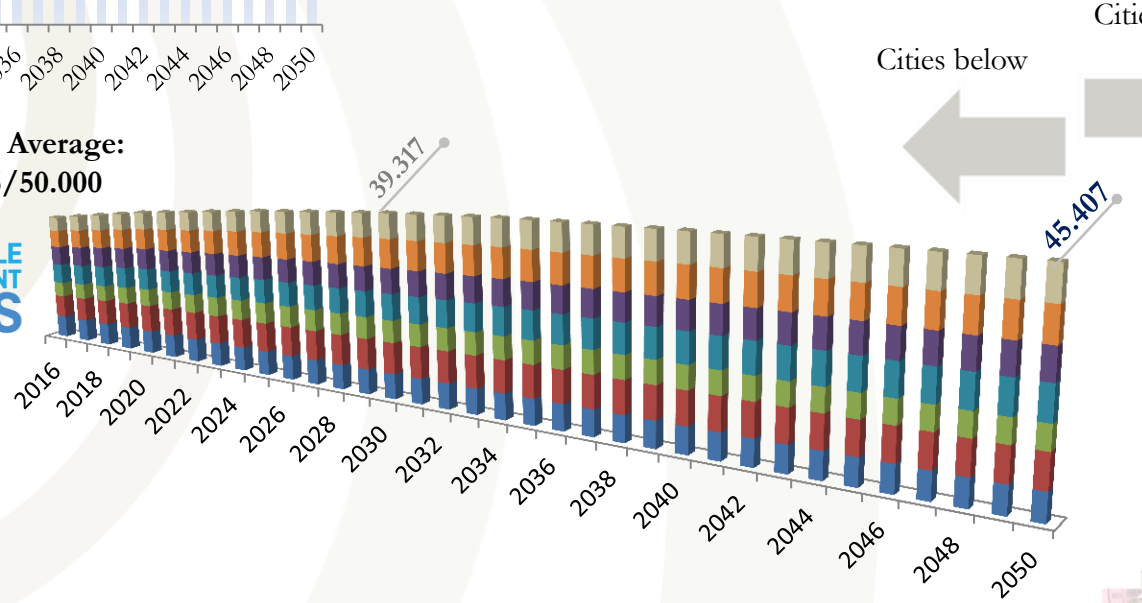


Convergence between the average and best possible performance

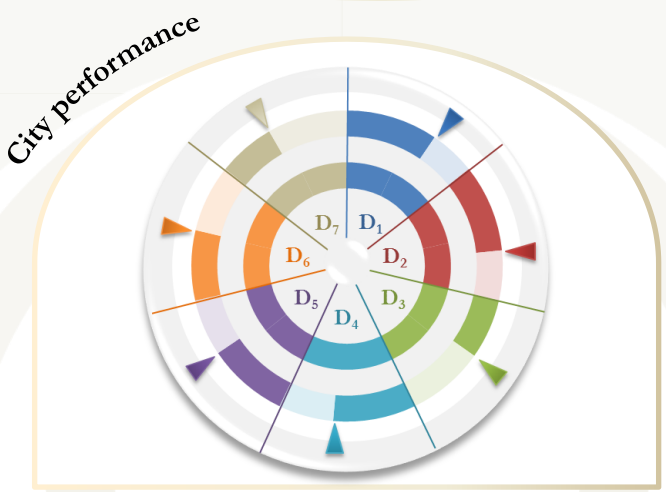
- Increase in the benchmark of cities with high levels of performance

Present Average: 28.416/50.000

SUSTAINABLE DEVELOPMENT GOALS



SDEWES Index Oriented Steps for Decision-Makers



1) Evaluate the overall score and dimension **performance of a specific city**

2) Consider solutions that will improve the value of **multiple indicators**

$\Delta < 0$

$\Delta = 0$

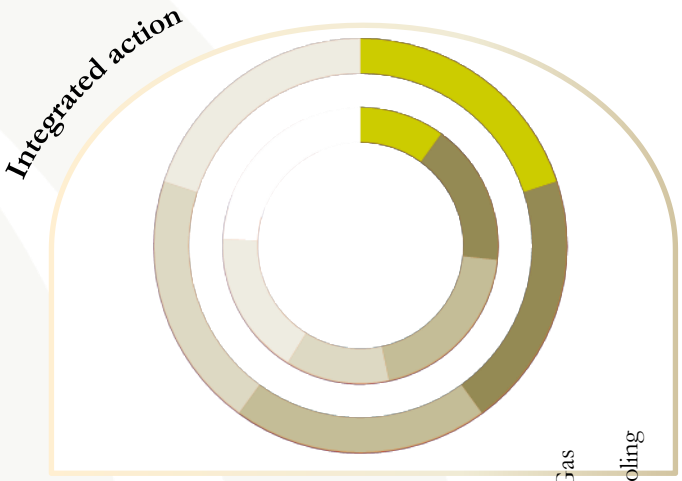
$\Delta > 0$

SDEWES Index Oriented Steps for Decision-Makers

Paired cities* Shared dimension quartile Shared index quartile

* Above or below the average in the same dimension across all dimensions

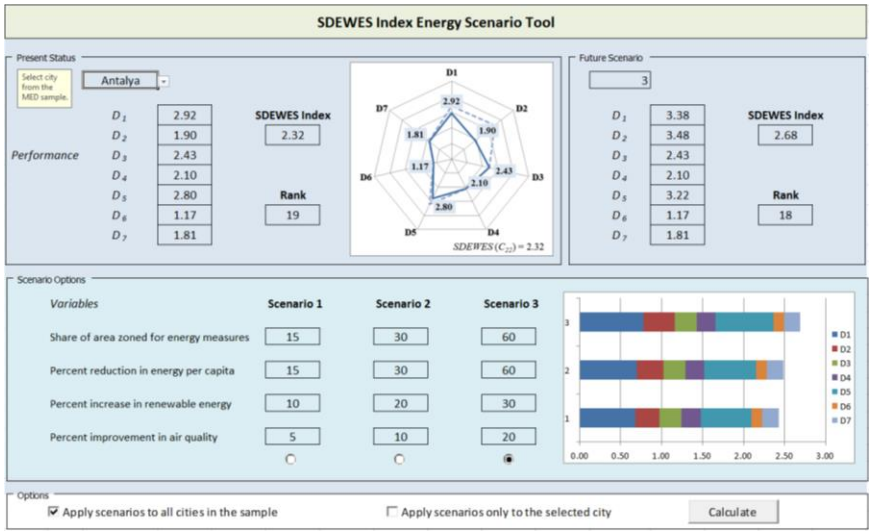
3) Identify cities with which to strengthen or initiate **collaborative efforts**



4) **Take integrated action** to increase the sustainability of development and re-evaluate

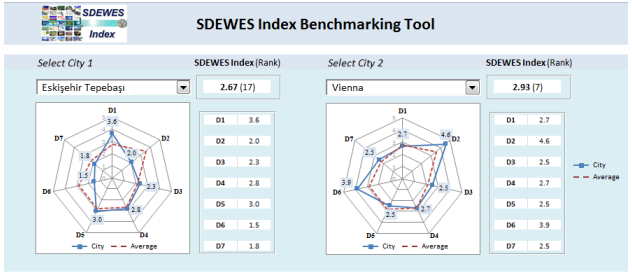
	Electricity/Gas	Heating/Cooling	Building Sector	Transport Sector	Urban Industry	Urban Utilities
Diffusion of urban renewable energy solutions in all sectors	✓	✓	✓	✓	✓	✓
• Renewable energy and electrofuels in public/private transport	✓			✓		✓
• The production of hydrogen gas from renewable energy sources	✓	✓	✓	✓	✓	✓
Increased opportunities for sharing waste heat in urban areas		✓	✓		✓	✓
Demand response, including in wastewater infrastructure	✓	✓	✓	✓	✓	✓
Material, energy, and water substitution within urban waste hierarchy	✓	✓	✓	✓	✓	✓
Co-location of energy and water utilities for resource exchanges	✓	✓	✓			✓
Improvements in urban planning to reduce climate risks	✓	✓	✓	✓	✓	✓

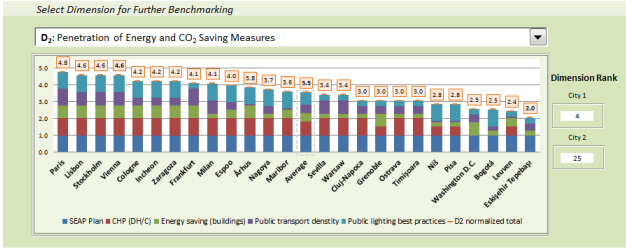
SDEWES Index Benchmarking Tools

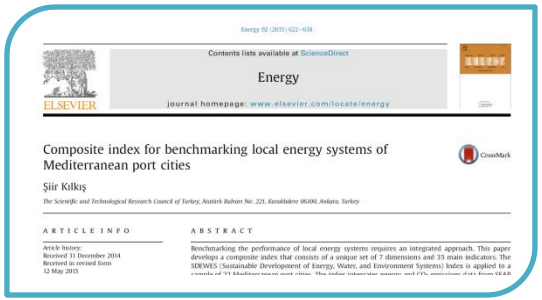


Related Benchmarking Tools

- Scenario comparison for a city
- Comparison of two cities







Pilot Projects and Developments from Sampled Cities

Pilot projects and developments for integrating the energy, water and environment systems and/or sectors

Budapest

A pilot 10 MW power-to-gas facility driven by flexible load is planned
~ 50 km to the city

Other examples:

- Hamburg (total 1815 kW)
- Berlin (total 500 kW)

Dubrovnik

Solar energy is utilized in the water works utility building as an example of the **co-location of energy and water sectors**

Murcia

A PEM fuel cell treating 10 m^3/h biogas from the WWTP of Murcia produces 3 kW_e based on methane dry reforming

Amsterdam

The **urban and inter-city rail network** is supplied by 100% renewable energy and those for stations are underway (including BIPV)

Århus

The city is transitioning to a **low temperature district heating network** with a sea-water based heat pump replacing peak boilers

Additional opportunity:
Demand response in the water sector
~ 10% primary energy savings

Pilot Projects and Developments from Sampled Cities

Pilot projects and developments for integrating the energy, water and environment systems and/or sectors

Christchurch

The airport uses 12°C ground water for cooling and heating that replaced the old diesel and LPG boilers

Funchal

Madeira seeks to be a **smart island system** that can receive support from the integration of sectors

Riga

The city plans to capture waste heat from wastewater to supply heat to **multi-apartment residential buildings**

Sydney

Plans to displace 2,365 GWh of coal-fired electricity with gas and/or thermal networks and 537 TJ from energy savings

Dublin

75% of the city is suitable for **district heating** in which such a scheme is planned to replace the individual use of natural gas

Additional opportunity:
Renewable energy based desalinization system

Source: Duić, N., Krajačić, G., da Graça Carvalho, M., RenewIslands methodology for sustainable energy and resource planning for islands, *Renewable and Sustainable Energy Reviews*

Pilot Projects and Developments from Sampled Cities

Pilot projects and developments for integrating the energy, water and environment systems and/or sectors

Reykjavík

The geothermal energy based **district heating** provides a total of 10,922 TJ to urban areas of which 10,041 TJ is for space heating

Hamburg

The **pilot district** of Reiherstieg is supplied by 100% RE while the local utility provides a 5% urban biogas share

Zagreb

Modernization of public transport vehicles, including **biodiesel utilization**, with additional opportunities from wastewater treatment

Izola

Small scale district heating systems are considered as future concepts, including **Sea-to-City hydrothermal** energy project

Copenhagen

The heating/cooling network is climate neutral with a target to be the **first climate neutral city in the world**

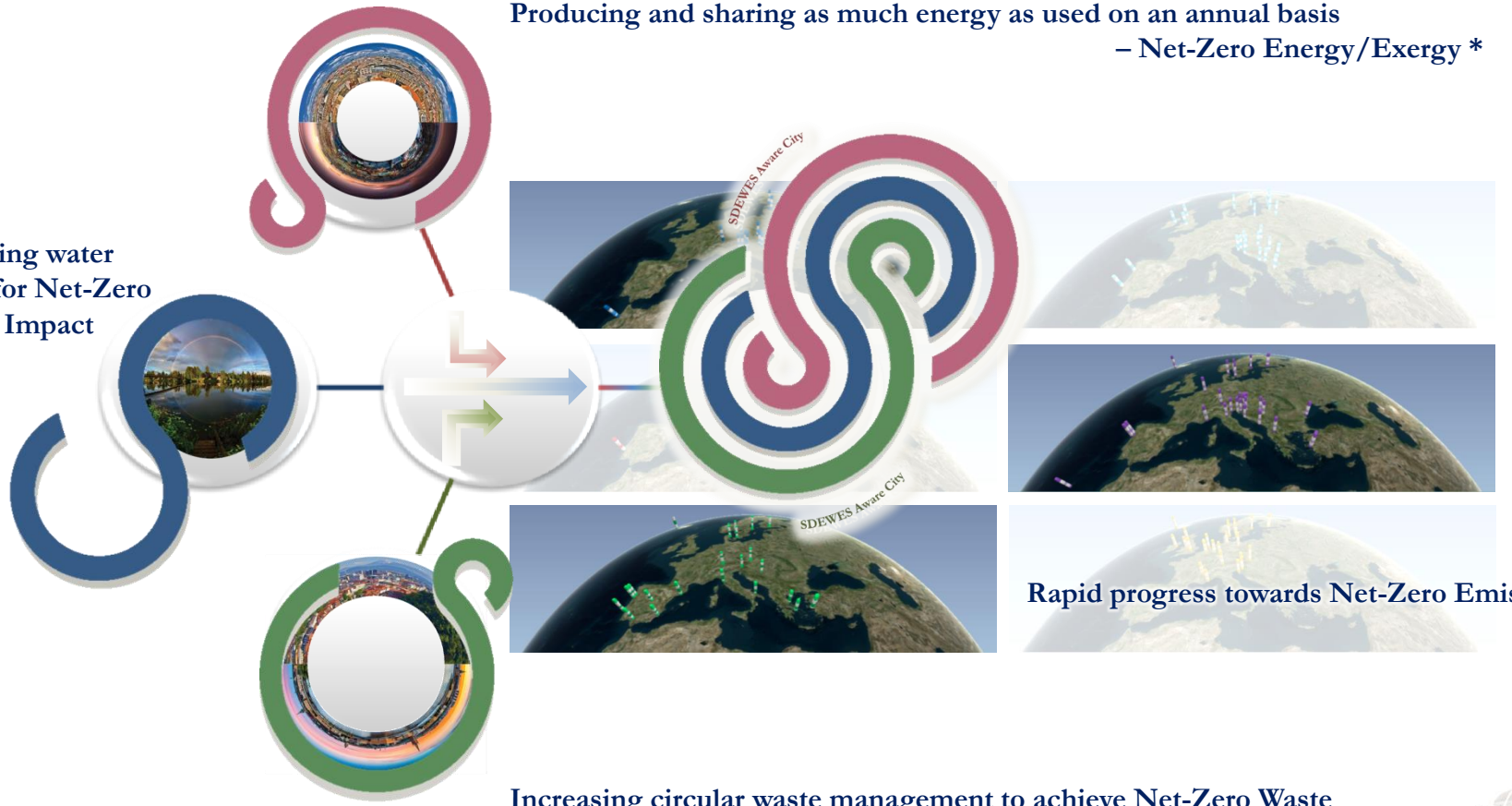
Other opportunities:

- Velika Gorica near Zagreb (~ 20 km)

Courage of Cities: SDEWES Future City Network

Producing and sharing as much energy as used on an annual basis – Net-Zero Energy/Exergy *

Preserving water resources for Net-Zero Water Impact

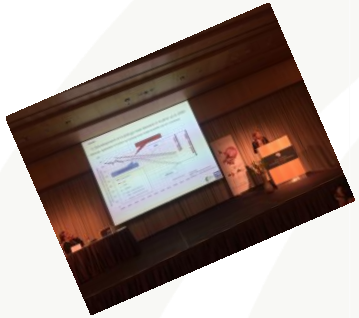


Rapid progress towards Net-Zero Emissions

Increasing circular waste management to achieve Net-Zero Waste

* **Source**: Kılkış, Ş., A Nearly Net-Zero Exergy District as a Model for Smarter Energy Systems in the Context of Urban Metabolism, JSDEWES

Cities Will Contribute to "Bending the Curve"



Word cloud based on the Scientific Programme

Plus all of the wealth of solutions that are propsed by SDEWES researchers!

Long Live our Planet Earth as We Know It!

A SDEWES Aware City is an **INTEGRATIVE** City

A SDEWES Aware City...
... is **YOUR** City

A SDEWES Aware City is a **COLLABORATIVE** City