UNIVERSITY OF RIJEKA
FACULTY OF ECONOMICS AND BUSINESS

Mia Dragović Matosović

# Advancing Sustainable City Planning: A Value-Based Decision Support Methodology for Prioritizing Energy and Climate Actions

DOCTORAL THESIS

Rijeka, 2026

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SVEUČILIŠTE U RIJECI

EKONOMSKI FAKULTET

Mia Dragović Matosović

# Unaprjeđenje održivog gradskog planiranja: Vrijednosna metodologija odlučivanja za prioritizaciju energetskih i klimatskih akcija

DOKTORSKI RAD

Mentor: Prof. dr. sc. Nela Vlahinić

Komentor: Stefan Bouzarovski, DPhil

Rijeka, 2026

Mentor: Prof. dr. sc. Nela Vlahinić, full professor at Faculty of economics and business, University of Rijeka

Co-mentor: Stefan Bouzarovski, DPhil, Professor of Human Geography, University of Manchester, UK

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**Advancing Sustainable City Planning: A Value-Based Decision Support Methodology for Prioritizing Energy and Climate Actions**

**Unaprjeđenje održivog gradskog planiranja: Vrijednosna metodologija odlučivanja za prioritizaciju energetskih i klimatskih akcija**

1. Izjavljujem da sam doktorsku disertaciju izradio/la samostalno pod mentorstvom prof. dr. sc. Nele Vlahinić, a pri izradi doktorske disertacije pomagao/la mi je i prof. Stefan Bouzarovksi, DPhil. U radu sam primijenila metodologiju znanstvenoistraživačkog rada i koristio/la literaturu koja je navedena na kraju rada. Tuđe spoznaje, stavove, zaključke, teorije i zakonitosti koje sam izravno ili parafrazirajući naveo/la u radu citirao/la sam i povezao/la s korištenim bibliografskim jedinicama sukladno odredbama Pravilnika o izradi i opremanju doktorskih radova Sveučilišta u Rijeci, Ekonomskog fakulteta u Rijeci. Rad je pisan u duhu hrvatskog jezika.

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# Summary

This dissertation presents the development and empirical application of SYNERGISE+, an analytical framework designed to support the prioritisation of sustainable climate actions in urban contexts. Grounded in multi-criteria decision analysis, the framework evaluates policy measures across five dimensions of sustainability—environmental, economic, social, technical, and institutional—structured through twelve normative criteria. Stakeholder preferences are systematically elicited through a pairwise comparison process, enabling value-informed rankings of actions and enhancing the transparency and consistency of decision-making.

The research advances a methodological approach to assess the internal coherence, synergy potential, and value alignment of Sustainable Energy and Climate Action Plans (SECAPs) across a sample of 45 European cities. Results indicate that economic viability remains the dominant policy focus, while environmental objectives are comparatively underprioritised—revealing a structural imbalance in prevailing urban sustainability strategies.

A key contribution lies in the identification of cross-dimensional synergies: 174 SECAP actions were classified into 47 thematic bundles, of which 21 demonstrate high potential for integrative mitigation–adaptation outcomes. This approach offers a replicable method for enhancing the efficiency and strategic alignment of local climate action. The findings underscore the relevance of structured, value-based assessment frameworks in addressing the persistent disconnect between policy ambition and implementation capacity in urban climate governance. To validate the framework, the model is applied to three European cities—Litoměřice, Maribor, and Zagreb. Results indicate that institutional and economic considerations dominate current planning practice, while social and technical dimensions are comparatively underemphasised.

The five-dimensional framework is further extended to align with the global Sustainable Development Goals (SDGs), enabling a cross-comparative analysis of sustainability performance across 45 EU cities and 167 countries. Mapping SDG targets onto the SYNERGISE+ dimensions reveals substantial regional disparities, with the economic dimension and technical feasibility identified as primary enablers of SDG progress. Among all variables assessed, GDP emerges as the strongest predictor of overall SDG performance.

In summary, this dissertation delivers a methodologically robust and policy-relevant contribution to urban sustainability planning. It provides a replicable model for integrating local actions with global development goals, and demonstrates the value of participatory, structured decision-making in addressing complex climate challenges.

# Prošireni sažetak na hrvatskom jeziku

## SAŽETAK

Ova disertacija predstavlja razvoj i primjenu SYNERGISE+ modela, inovativnog okvira za odlučivanje osmišljenog u svrhu povećanja učinkovitosti urbanog održivog i klimatskog planiranja. Gradovi, kao glavni izvori emisija i mjesta gdje živi većina svjetskog stanovništva, ključni su za provedbu globalne agende održivog razvoja i igraju presudnu ulogu u suočavanju s klimatskim izazovima. Planovi održive energije i klimatskih mjera (SECAP), u okviru inicijative Sporazum gradonačelnika Europske unije, predstavljaju glavni alat kojim gradovi planiraju, provode i prate mjere ublažavanja i prilagodbe klimatskim promjenama.

Model SYNERGISE+, razvijen u okviru programa Horizon 2020 (projekt PROSPECT+), predstavlja strukturirani i normativno utemeljen višekriterijski alat za odlučivanje (MCDA), osmišljen kako bi omogućio vrednovanje i prioritizaciju klimatskih mjera na razini gradova u skladu s lokalnim vrijednostima, institucionalnim kapacitetima i strateškim ciljevima. Za razliku od konvencionalnih sektorskih pristupa, SYNERGISE+ se fokusira na razinu pojedinačnih mjera te omogućuje ex-ante vrednovanje njihove održivosti kroz pet dimenzija: okolišnu, ekonomsku, društvenu, tehničku i institucionalnu, koje su operacionalizirane u dvanaest jasno definiranih kriterija drugog reda. Ova struktura omogućuje transparentno rangiranje mjera temeljem kombinacije kvantitativnih i kvalitativnih pokazatelja, uz uključivanje preferencija lokalnih dionika kroz participativnu metodu uparene usporedbe.

Posebna inovacija SYNERGISE+ modela jest uvođenje sinergijskog faktora u ocjenu mjera, čime se omogućuje istodobna evaluacija mjera ublažavanja i prilagodbe klimatskim promjenama. Analizom 174 najčešće korištene mjere iz postojećih SECAP-a, izrađen je katalog koji grupira mjere u 47 tematskih skupina, od kojih 21 pokazuje izražen potencijal za sinergijsko djelovanje. Prepoznavanjem ovih međudjelovanja omogućava se bolja integracija klimatskih ciljeva, racionalnija alokacija resursa i povećana isplativost provedbe. Primjena modela na tri stvarna grada – Zagreb, Maribor i Litoměřice – te na dva hipotetska grada, potvrdila je njegovu fleksibilnost, robusnost i mogućnost prilagodbe različitim strateškim usmjerenostima. Rezultati upućuju na to da institucionalni i ekonomski čimbenici trenutačno prevladavaju u odlučivanju o urbanim klimatskim mjerama, dok su društveni i tehnički aspekti često nedovoljno zastupljeni.

Analiza težina koje su dionici dodijelili pojedinim kriterijima otkrila je prevlast ekonomskih i institucionalnih faktora u odlučivanju o klimatskim mjerama, dok su društvene i tehničke dimenzije često podcijenjene, unatoč njihovoj deklarativnoj važnosti. Model je testiran kroz četiri scenarija vrijednosnih preferencija – uravnoteženi, održivi, konvencionalni i tehnokratski – koji simuliraju različite strategijske pristupe planiranju. Rezultati scenarijske analize pokazuju da se 76 % najviše rangiranih mjera zadržalo unutar prvih 10 prioriteta u svim scenarijima, čime se potvrđuje stabilnost i metodološka pouzdanost modela.

SYNERGISE+ dodatno je primijenjen na širu razvojnu razinu kroz mapiranje dimenzija okvira na 17 ciljeva održivog razvoja. Usporednom analizom 45 europskih gradova i 167 država identificirani su ključni strukturni uzroci uspjeha ili zaostajanja u ostvarivanju SDG ciljeva. Ekonomija i tehnička izvedivost pokazali su se kao najvažniji prediktori, pri čemu BDP predstavlja najsnažniji pokazatelj ukupne izvedbe, dok su društvene i okolišne dimenzije često marginalizirane u evaluacijskim okvirima. Ova strukturalna neuravnoteženost ukazuje na potrebu redefiniranja pristupa evaluaciji održivosti i jačanja uloge neekonomskih kriterija u donošenju odluka.

Usporedba SYNERGISE+ modela s postojećim institucionalnim alatima, poput EBRD Green City Action Plan (GCAP), ukazuje na nekoliko ključnih razlika i komplementarnih elemenata. Dok GCAP koristi sektorski pristup usmjeren na infrastrukturne investicije, s fokusom na kvantitativne indikatore i usporedna vrednovanja performansi gradova, SYNERGISE+ djeluje na razini konkretnih projekata i mjera, omogućujući dublju lokalnu prilagodbu i uključivanje kvalitativnih aspekata. GCAP-ov model, iako iznimno vrijedan za identificiranje ekoloških problema i usklađivanje s međunarodnim standardima, nedovoljno uzima u obzir kontekstualne vrijednosti, sinergije među mjerama i participaciju građana u odlučivanju. SYNERGISE+ nadopunjuje te praznine uvođenjem normativnog vrednovanja, sudioničkog odlučivanja i evaluacije mjera koje kombiniraju financijsku izvedivost s društvenom i okolišnom pravednošću.

Sukladno provedenim analizama i testiranjima, SYNERGISE+ model nudi konkretne smjernice za unaprjeđenje postojećih planerskih praksi. Preporučuje se institucionalizacija vrednovanja temeljena na vrijednostima, sustavno prepoznavanje sinergija među mjerama, uvođenje redovitih lokalnih procjena napretka prema SDG ciljevima te jačanje tehničkih i društvenih kapaciteta lokalnih vlasti. Nadalje, model pokazuje da participativne metode poput uparene usporedbe mogu uspješno balansirati između analitičke preciznosti i jednostavnosti primjene, čime se povećava legitimnost i provedivost odabranih mjera.

Disertacija također naglašava važnost ex-ante evaluacije mjera, za razliku od retrospektivnih pristupa koji dominiraju postojećim praksama. Korištenjem SYNERGISE+ modela moguće je već u fazi planiranja identificirati mjere koje imaju visoki sinergijski potencijal, optimalan povrat na ulaganje i društvenu prihvatljivost. Primjeri ušteda do 11,7 milijuna eura u gradu Litoměřice ukazuju na konkretne financijske koristi koje proaktivno planiranje može donijeti.

U konačnici, SYNERGISE+ predstavlja doprinos teorijskom i praktičnom području urbane održivosti. Nudi alat koji nadilazi tehničke okvire i uvodi filozofiju planiranja usmjerenu na uključivost, transparentnost i usklađenost s lokalnim vrijednostima. U vremenu kada su gradovi suočeni s kompleksnim izazovima i višestrukim krizama, ovakvi alati predstavljaju ključne instrumente za prevođenje političkih ambicija u održive i pravedne akcije. SYNERGISE+ ne zamjenjuje postojeće strateške dokumente, već ih obogaćuje pružajući metodu koja omogućuje informirano, kontekstualno osjetljivo i participativno planiranje u službi održive budućnosti gradova.

## UVOD

Ubrzane klimatske promjene, sve češće ekološke i socioekonomske krize te globalna nastojanja u okviru Ciljeva održivog razvoja (SDG) postavljaju pred gradove kompleksne zahtjeve u pogledu održivog planiranja. Gradovi, kao središta potrošnje resursa, emisija stakleničkih plinova i društvenih nejednakosti, prepoznati su kao ključni akteri u borbi protiv klimatskih promjena. Istodobno, upravo gradski prostori nude najviše potencijala za inovativne, integrirane i participativne pristupe održivom razvoju.

U europskom kontekstu, značajan instrument za operativizaciju lokalnih klimatskih strategija predstavljaju *Planovi održive energije i klimatskih promjena* (SECAP), razvijeni u okviru Inicijative Sporazuma gradonačelnika. SECAP-i formaliziraju pristup lokalnih vlasti u provedbi mjera ublažavanja i prilagodbe klimatskim promjenama te sve više uključuju ciljeve energetske učinkovitosti, kružnog gospodarstva, otpornosti zajednica i socijalne pravednosti. Međutim, brojni gradovi suočavaju se s izazovima u fazi odabira i provedbe konkretnih mjera – kako zbog nedostatka jasnog metodološkog okvira za određivanje prioriteta, tako i zbog nedovoljno izražene usklađenosti između lokalnih vrijednosti, strateških ciljeva i raspoloživih resursa.

S obzirom na navedeno, postoji potreba za alatima koji ne samo da omogućuju strukturirano i transparentno odlučivanje, već i reflektiraju lokalne vrijednosti, kontekstualne uvjete te potencijalne sinergije između različitih klimatskih ciljeva. Upravo iz tog razloga razvijen je model SYNERGISE+, koji se u ovoj disertaciji primjenjuje kao znanstveni okvir za evaluaciju i prioritizaciju lokalnih klimatskih mjera. Cilj modela nije zamjena postojećih strateških dokumenata, već njihova nadogradnja – kroz uvođenje normativno utemeljenog višekriterijskog sustava odlučivanja koji je istovremeno transparentan, fleksibilan i orijentiran na stvarne potrebe lokalne zajednice.

## CILJEVI ISTRAŽIVANJA

Cilj ove doktorske disertacije bio je razviti i primijeniti normativno utemeljen analitički okvir za donošenje odluka – SYNERGISE+ – s naglaskom na podršku lokalnim vlastima u određivanju prioriteta klimatskih i energetskih mjera unutar planova održive energije i klimatskih promjena (SECAP). S obzirom na čestu fragmentaciju između mjera ublažavanja i prilagodbe, model je zamišljen kao alat za prepoznavanje i evaluaciju sinergijskih učinaka između tih mjera, uz istovremeno usklađivanje sa specifičnim lokalnim vrijednostima i globalnim razvojnim ciljevima.

Konkretno, istraživanjem se željelo odgovoriti na sljedeće ključno istraživačko pitanje:

**Na koji način višekriterijski alati za odlučivanje mogu unaprijediti sposobnost lokalnih vlasti da definiraju održive klimatske mjere koje su međusobno usklađene, sinergijske i vrijednosno usmjerene?**

Disertacija se temelji na sljedećim hipotezama:

- **H1:** Postojeći alati za planiranje i indeksi rijetko pružaju integrirani skup kriterija održivosti za zajedničku evaluaciju mjera ublažavanja i prilagodbe.
- **H2:** Metoda uparene usporedbe učinkovita je u hvatanju preferencija dionika u lokalnom klimatskom planiranju, uravnotežujući jednostavnost i analitičku preciznost pri određivanju težina kriterija.
- **H3:** Uključivanje preferencija lokalnih dionika u modele bodovanja poboljšava usklađenost prioritiziranih mjera s ciljevima održivosti specifičnim za pojedini grad.
- **H4:** Ekonomski indikatori i dalje dominiraju evaluacijom održivosti u indeksima povezanima sa SDG-ovima, pri čemu često zasjenjuju društvene i okolišne kriterije.
- **H5:** Većina SECAP-a ne uspijeva sustavno identificirati ili integrirati sinergije između mjera ublažavanja i prilagodbe.
- **H6:** U praksi, prioritizaciju mjera u SECAP-ima snažnije oblikuju financijska i politička izvedivost nego okolišni ili društveni kriteriji.

Model SYNERGISE+ konstruiran je da bude dovoljno fleksibilan za primjenu u različitim gradskim kontekstima, ali i dovoljno strukturiran da omogući usporedbu rezultata unutar šire europske perspektive.

## ZNANSTVENI DOPRINOS I OČEKIVANI REZULTATI

Ova disertacija razvija metodologiju za prioritizaciju i odabir mjera iz lokalnih planova održivosti, s integracijom sinergija između mjera ublažavanja i prilagodbe klimatskim promjenama. Time se adresiraju postojeće praznine u održivom urbanom planiranju te se lokalnim vlastima nudi strukturirani okvir za donošenje odluka koji povećava učinkovitost provedbe klimatskih i energetskih mjera. Doprinosi su trostruki – konceptualni, empirijski i metodološki.

### Konceptualni doprinos: Integracija sinergija u odlučivanje

Disertacija uvodi inovativni okvir odlučivanja koji u model višekriterijske analize (MCDA) uključuje varijablu za procjenu potencijala sinergije između mjera, čak i kada njihovi učinci nisu izravno kvantificirani. Takav pristup omogućuje integrirano donošenje odluka u skladu s ciljevima EU i UN, za razliku od klasičnih modela koji ublažavanje i prilagodbu tretiraju odvojeno. Model SYNERGISE+ integrira objektivne indikatore (npr. uštede energije, smanjenje emisija) i subjektivne čimbenike (npr. politička izvedivost, sudjelovanje dionika), pružajući sveobuhvatan alat za odlučivanje usklađen s lokalnim kontekstom.

SYNERGISE+ uključuje: (1) set kriterija za ublažavanje i prilagodbu, (2) sustav ponderiranja temeljen na lokalnim vrijednostima, (3) katalog 67 tipičnih mjera s označenim sinergijama, te (4) usklađenost s EU Taksonomijom. Za razliku od retrospektivnih pristupa, SYNERGISE+ omogućuje ex-ante evaluaciju, odnosno vrednovanje prije provedbe. Iako je procjena sinergijskog učinka indikativna (prosječna ušteda 5 %), nalazi pokazuju znatan potencijal, s preliminarnim procjenama ušteda do 11,7 milijuna eura u Litoměřicama. Više od 80 % mjera u analiziranim gradovima (Zagreb, Maribor, Litoměřice) ima izražen sinergijski potencijal.

**Empirijski doprinos: Evaluacija utjecaja sinergija na odlučivanje**

Empirijska primjena modela potvrđuje da prepoznavanje sinergija značajno utječe na rangiranje mjera i konačne odluke. Istraživanje:

- Povezuje mjere prilagodbe i ublažavanja s ciljem smanjenja troškova i povećanja učinkovitosti.
- Analizira promjene prioriteta u SECAP-ima uslijed uvođenja sinergijskog kriterija.
- Ispituje učinak različitih tehnika vrednovanja težina (npr. uparena usporedba) u realnim gradskim kontekstima.

Rezultati potvrđuju da je predložena metodologija primjenjiva u praksi i omogućuje transparentno, ponovljivo odlučivanje.

**Metodološki doprinos: Unaprjeđenje metoda za lokalno planiranje**

SYNERGISE+ je osmišljen kao strukturiran, a istovremeno jednostavan okvir za podršku lokalnim vlastima u izradi i provedbi SECAP-a. Ključne metodološke novosti uključuju:

- Višestruku primjenu: u fazi planiranja (vrednovanje mjera) i predfazi implementacije (alokacija resursa).
- Dvoetažni kriterijski okvir: strateške i operativne dimenzije omogućuju procjenu kompromisa prilagođenu kapacitetima pojedinog grada.
- Participativni pristup: uključivanje lokalnih dionika u određivanje težina povećava legitimitet i učinkovitost implementacije.

- Baza od 174 unaprijed definirane mjere (58 prilagodbe, 116 ublažavanja), pogodna za gradove s ograničenim tehničkim kapacitetima.
- Kvalitativna matrica učinaka: omogućuje vrednovanje nefinancijskih koristi kao što su zdravlje, otpornost i društvena uključenost.

Usklađenost SYNERGISE+ s EU Taksonomijom omogućuje gradovima da klimatske mjere vrednuju izvan okvira emisija $CO_2$, integrirajući aspekte otpornosti, društvene pravednosti i pravedne energetske tranzicije.

## METODOLOGIJA (POSTUPCI)

Istraživačka metodologija temelji se na višekriterijskoj analizi odlučivanja (MCDA), integriranoj s participativnim vrednovanjem koje uključuje lokalne dionike. Metodološki pristup može se sažeti u četiri glavne faze:

1. **Dizajn okvira SYNERGISE+**: Razvijen je petodimenzionalni model cjelovite održivosti koji uključuje okolišne, ekonomske, društvene, tehničke i institucionalne aspekte. Svaka dimenzija operacionalizirana je kroz specifične kriterije.
2. **Elicitacija vrijednosti**: Metoda uparene usporedbe korištena je za dobivanje težina pojedinih kriterija. Sudionici (lokalni akteri) rangirali su važnost kriterija prema lokalnim prioritetima.
3. **Procjena mjera i prepoznavanje mogućih sinergija**: 174 klimatske mjere grupirane su u 47 tematskih skupina. Grupiranje mjera omogućava prepoznavanje mogućih sinergija među mjerama mitigacije i adaptacije. Svaka mjera ocijenjena je kroz kompenzacijski model bodovanja u skladu s dobivenim težinskim faktorima.

## REZULTATI

### Razvoj SYNERGISE+ originalne matrice odlučivanja

U središtu modela SYNERGISE+ nalazi se višekriterijska matrica odlučivanja razvijena kako bi omogućila sustavno vrednovanje klimatskih i energetskih mjera u urbanim sredinama. Ova matrica oblikovana je s ciljem da reflektira stvarne izazove i vrijednosne prioritete lokalnih vlasti, istodobno pružajući metodološki utemeljen okvir za evaluaciju mjera prema načelima održivog razvoja. Temelji se na pet ključnih dimenzija održivosti: okolišnoj, ekonomskoj, društvenoj, tehničkoj i institucionalnoj, koje su operacionalizirane kroz ukupno dvanaest kriterija drugog reda.

**Tablica 1:** Popis dimenzija i kriterija SYNERGISE+ matrice odlučivanja.

| Br. | Dimenzije | Kriteriji drugog reda |
|---|---|---|

| | | |
|---|---|---|
| 1 | OKOLIŠNI UTJECAJ | 1. Smanjenje emisija i učinkovitost resursa<br>2. Očuvanje bioraznolikosti<br>3. Rizik i ranjivost |
| 2 | EKONOMSKA ODRŽIVOST | 4. Povrat na ulaganje<br>5. Ekonomski učinak<br>6. Provedba i upravljanje |
| 3 | DRUŠTVENA PRAVEDNOST | 7. Jednakost / pravednost i dostupnost<br>8. Kvaliteta života i javno zdravlje |
| 4 | TEHNIČKA IZVEDIVOST I KONKURENTNOST | 9. Tehnološka zrelost i potencijal recikliranja<br>10. Inovacijski i edukacijski potencijal |
| 5 | INSTITUCIONALNI OKVIR | 11. Politički i pravni okvir<br>12. Politička prihvatljivost |

*Izvor: Autor*

Svi kriteriji unutar matrice ponderiraju se pomoću metode **uparene usporedbe**, čime se osigurava da konačno rangiranje mjera reflektira stvarne preferencije lokalnih dionika kroz samo 19 jednostavnih odgovora. Kombinacija kvantitativnih i kvalitativnih komponenti u matrici omogućava fleksibilnost u primjeni, kao i prilagodbu različitim kontekstima, razinama razvijenosti i institucionalnim kapacitetima gradova. Time SYNERGISE+ nudi jedinstveni alat koji povezuje vrijednosnu orijentaciju, znanstvenu utemeljenost i praktičnu izvedivost u procesu donošenja odluka o održivom gradskom razvoju.

Razvoj matrice započeo je temeljitom analizom više od 50 postojećih okvira i indeksa održivosti u urbanom planiranju, s ciljem identifikacije najčešće korištenih kriterija koji su znanstveno i praktično relevantni. Paralelno s pregledom literature provedena je i kvalitativna validacija kroz konzultacije s dionicima i stručnjacima uključenima u provedbu SECAP-a i inicijative PROSPECT+. Time su odabrani kriteriji dobili potvrdu o svojoj relevantnosti u stvarnom kontekstu lokalnog planiranja.

**Pregled postojećih okvira i indeksa održivosti**

Razvoj SYNERGISE+ modela utemeljen je na potrebi za instrumentom koji nadilazi ograničenja postojećih indeksa održivosti. Iako su brojni indeksi razvijeni kako bi podržali gradske vlasti u planiranju i procjeni održivosti, većina njih ne omogućuje integriranu evaluaciju mjera ublažavanja i prilagodbe, niti pružaju alate za određivanje prioriteta na razini konkretnih mjera, što je ključno za učinkovitu provedbu SECAP-a.

**Tablica 2:** Pregled trinaest postojećih relevantnih indeksa i okvira za održivost.

| **Okvir održivosti** | **Godina** | **Kratki opis** | **Autor / Izvor** |
|---|---|---|---|
| CDP ICLEI Track – Zajednički okvir za izvještavanje | 2018. | Partnerstvo između CDP-a i ICLEI-ja koje pruža platformu za gradove radi prijave okolišnih podataka i praćenja napretka klimatskih aktivnosti. Od 2024. godine upitnik za gradove usklađen je s obvezama izvještavanja više inicijativa, uključujući GHG protokol i kampanje UNFCCC-a. | www.cdp.net/en (CDP and ICLEI, 2023) |
| EBRD Metodologija za zelene gradske akcijske planove (GCAP) | 2016. | Strateški okvir sa 114 pokazatelja koji procjenjuju urbane okolišne izazove kroz 20 kategorija u sektorima poput energije, prometa, vode, otpada i korištenja zemljišta. Utemeljen na modelu Pritisak–Stanje–Odziv (PSR), GCAP kvantitativno procjenjuje okolišna pitanja i identificira odgovarajuće politike i investicijske mjere. Iako je metodologija primarno okolišno orijentirana, omogućuje i kvalitativnu identifikaciju mjera koje pozitivno doprinose društvenim ciljevima i gospodarskom rastu. | https://www.ebrdgreencities.com/assets/Uploads/PDF/Green-City-Action-Plan-Methodology.pdf (EBRD, 2016) |
| ECPI – Interakcije energetskih i klimatskih politika | 2006. | Alat za kvalitativnu ex-ante procjenu međudjelovanja energetskih i klimatskih instrumenata u gradovima u okviru četiri cilja: ublažavanje klimatskih promjena, energetska učinkovitost, društveno-gospodarska konkurentnost i tehnologija. | (Oikonomou and Jepma, 2008) |
| EUGCI – EU Zeleni gradski indeks | 2009. | Sustav rangiranja pokrenut od strane Siemensa za procjenu okolišne učinkovitosti europskih gradova, uključujući energiju, vodu, kvalitetu zraka i gospodarenje otpadom. | (Economist Intelligence Unit, 2009) |

| **Okvir održivosti** | **Godina** | **Kratki opis** | **Autor / Izvor** |
|---|---|---|---|
| InSMART – Integrirano pametno planiranje gradova | 2017. | Metodologija financirana iz EU sredstava koja kombinira kvantitativno modeliranje i sudioničko uključivanje dionika za dekarbonizaciju gradova i optimizaciju pametnog urbanog razvoja kroz integraciju planiranja energije, prometa i korištenja zemljišta. | http://www.insmartenergy.com (Gargiulo *et al.*, 2017) |
| Life SEC ADAPT – Projekt LIFE programa za klimatsku prilagodbu u općinama | 2019. | Projekt unutar programa LIFE usmjeren na jačanje kapaciteta lokalnih samouprava u planiranju klimatske prilagodbe diljem Europe. | www.lifesecadapt.eu (Life SEC Adapt Project, 2019) |
| PROSPECT okvir za procjenu sposobnosti gradova | 2020. | Integrirani okvir razvijen u okviru projekta Horizon 2020 PROSPECT, koji mjeri uspješnost gradova u provedbi održivih mjera, s fokusom na planiranje, financiranje i provedbene kapacitete. | https://h2020prospect.eu/ (Spyridaki *et al.*, 2020) |
| RFSC – Referentni okvir za održive gradove | 2016. | Europski okvir za planiranje i upravljanje urbanom održivošću koji pruža smjernice gradovima za razvoj integriranih i održivih urbanih strategija usklađenih s politikama EU. | http://www.rfsc.eu/ (Cerema, 2016) |
| SDG EU Cities Index | 2018. | Prototip indeksa koji mjeri napredak europskih gradova prema ostvarivanju 15 od 17 ciljeva održivog razvoja UN-a. | euro-cities.sdgindex.org/ (Lafortune *et al.*, 2019) |
| SDEWES – Indeks održivog razvoja sustava energije, vode i okoliša | 2002. | Okvir za evaluaciju urbane održivosti s fokusom na integraciju energetskih, vodoopskrbnih i okolišnih sustava. | https://www.sdewes.org/ (Kilkiş, 2015) |

| **Okvir održivosti** | **Godina** | **Kratki opis** | **Autor / Izvor** |
|---|---|---|---|
| Metodologija za procjenu pametnih i održivih gradova | 2015. | Multidimenzionalno rangiranje održivosti za pametne megagradove s 20 kriterija raspoređenih u 8 dimenzija, temeljenih na održivosti i tehnološkoj inovaciji. | (Shmelev and Shmeleva, 2019) |
| Smart Florence Plan | 2014. | Strategija pametnog i održivog urbanog razvoja u Firenci, Italija. | (Comune di Firenze, 2015) |
| SSI – Indeks održivog društva | 2006. | Okvir za mjerenje održivosti gradova i država temeljen na pokazateljima društvene, okolišne i ekonomske dobrobiti. | www.ssfindex.com/ (Van de Kerk and Manuel, 2008) |

U ovoj analizi prikazane su ključne razlike između SYNERGISE+ i trinaest najčešće korištenih urbanih indeksa, uključujući CDP-ICLEI Track, RFSC, SDEWES, SSI, InSMART i dr.

### 1. Dimenzije i pokrivenost kriterija

Većina postojećih indeksa fokusira se na tri temeljne dimenzije održivosti – okolišnu, ekonomsku i, u manjoj mjeri, društvenu. Uočeno je da tehnička izvedivost i institucionalna sposobnost rijetko ulaze u metodološki okvir evaluacije, iako su ključne za implementaciju lokalnih mjera. SYNERGISE+ nadilazi ovu ograničenost uvođenjem petodimenzionalnog modela koji integrira političku izvedivost, pravni okvir i tehnološku zrelost, što ga čini pogodnim za realne potrebe urbanih vlasti

### 2. Tip evaluacije: ciljevi vs. mjere

Indeksi poput SDG EU Cities i RFSC služe uglavnom za praćenje napretka u ostvarenju ciljeva održivosti koristeći agregirane pokazatelje. Nasuprot tome, SYNERGISE+ omogućuje evaluaciju na razini pojedinačnih mjera, što ga čini posebno korisnim za faze planiranja i odabira akcija u SECAP-ima, a ne samo za ex-post praćenje provedbe.

### 3. Metodološki pristup: kvalitativno, kvantitativno, hibridno

Dok su indeksi poput CDP ICLEI Track i EUGCI izrazito kvantitativni, a RFSC se oslanja na dostupne statističke podatke, SYNERGISE+ koristi hibridni pristup koji kombinira kvantitativne podatke i kvalitativno vrednovanje tamo gdje podaci nedostaju. Ovaj pristup omogućuje uključivanje mjera za koje nisu dostupni egzaktni financijski ili tehnički parametri, ali su strateški važni.

### 4. Participativnost i refleksija lokalnih vrijednosti

Većina postojećih indeksa koristi standardizirane kriterije bez direktnog uključivanja lokalnih dionika. SYNERGISE+ omogućuje određivanje težina kriterija putem metode uparene usporedbe, čime se preferencije dionika ugrađuju u proces odlučivanja, čime se povećava legitimnost i lokalna relevantnost odluka.

### 5. Evaluacija sinergija

SYNERGISE+ je jedini identificirani model koji sistematski mapira sinergijske učinke između mjera ublažavanja i prilagodbe. Ostali indeksi ne uključuju ovu dimenziju, iako istraživanja pokazuju da upravo sinergije mogu rezultirati znatnim uštedama i učinkovitijom provedbom klimatskih strategija.

### Zaključno promišljanje

Analiza ukazuje da SYNERGISE+ nadopunjuje praznine u postojećim okvirima kroz uvođenje evaluacije mjera (a ne samo ciljeva), participativno vrednovanje, uključivanje sinergijskih učinaka i pokrivenost tehničkih i institucionalnih aspekata. Na taj način ne predstavlja konkurenciju, već nadogradnju postojećim pristupima, pogotovo u kontekstu donošenja konkretnih odluka o alokaciji ograničenih resursa na gradskoj razini. Okolišna dimenzija obuhvaća kriterije usmjerene na smanjenje emisija i učinkovitost korištenja resursa, očuvanje bioraznolikosti te otpornost na klimatske rizike i ranjivosti. Ova dimenzija procjenjuje izravne učinke mjera na okoliš, ali i njihovu dugoročnu održivost u kontekstu klimatskih promjena.

**Ocjenjivanje mjera i normalizacija u svrhu rangiranja**

U okviru modela SYNERGISE+ kvalitativno bodovanje alternativnih mjera provodi se pomoću petostupanjske ordinalne skale: veliki pozitivan učinak, mali pozitivan učinak, bez učinka, mali negativan učinak, veliki negativan učinak. Za izračun ukupnog rezultata koristi se metoda **Simple Additive Weighting (SAW)**, koja podrazumijeva zbrajanje ponderiranih bodova prema unaprijed određenim težinama kriterija. Iako su kompenzacijski modeli poznati po mogućim pristranostima, SAW metoda je odabrana zbog svoje transparentnosti, jednostavne primjene i interpretativnosti u lokalnom planiranju.

U svrhu osiguravanja usporedivosti između različitih kriterija, korištena je **maksimalno-linearna normalizacija**, koja pokazuje veću stabilnost u odnosu na alternativne pristupe poput vektorske normalizacije. Ova metoda smanjuje utjecaj ekstremnih vrijednosti i omogućuje konzistentnu integraciju kvantitativnih podataka u matricu odgovora.

Dodatno, razvijena su **četiri scenarija vrijednosnih preferencija** radi simulacije različitih pristupa planiranju:

- **Uravnoteženi scenarij** – svi kriteriji imaju jednaku važnost.
- **Konvencionalni scenarij** – naglasak na političkoj prihvatljivosti i povratu ulaganja, uz zanemarivanje bioraznolikosti i rizika.
- **Održivi scenarij –** prioritet se daje okolišnim i društvenim ciljevima, neovisno o troškovima ili institucionalnim ograničenjima.
- **Ekstremni scenarij** – simulacija maksimalne varijabilnosti težina radi testiranja robusnosti modela.

Tablica scenarija pokazuje značajne razlike u rangiranju kriterija između scenarija, čime se ilustrira kako promjena preferencija može utjecati na prioritizaciju mjera. Model zatim procjenjuje uspješnost svake mjere kroz agregirani rezultat na ljestvici od 0 do 1; mjere s rezultatom većim od **0,62** smatrane su snažnim kandidatima za provedbu jer pokazuju pozitivan učinak prema većini kriterija.

Primjenom na tri stvarna SECAP-a i dva hipotetska grada, model je testiran u pogledu mogućnosti otkrivanja prioriteta donošenja odluka i osjetljivosti na promjene u težinama kriterija.

Cilj je bio testirati može li model SYNERGISE+ točno odražavati strateške prioritete stvarnih SECAP-ova kada se primijeni na postojeće gradske planove te procijeniti stabilnost i osjetljivost rangiranja kroz različite scenarije vrijednosti. Rezultati su sažeti u Tablici 2, dok je potpuna analiza dostupna u Prilogu C.

Nalazi ukazuju da je, u prosjeku, 79% mjera doživjelo promjene rangova u različitim scenarijima. Međutim, kada se analiziraju mjere najvišeg ranga, otkriveno je da je 76% mjera ostalo unutar top 10, dok je 82% zadržalo svoje mjesto unutar top 20. Prosječan pomak u rangu (bilo unaprijed ili unazad) iznosio je šest mjesta, što potvrđuje robusnost modela u održavanju konzistentnosti, dok omogućuje prilagodbe temeljem scenarija.

**Tablica 2:** Analiza osjetljivosti triju scenarija SYNERGISE+

| Analiza osjetljivosti scenarija | Prosječni rezultati svih scenarija |
|---|---|
| Distribucija rangova: % mjera koje su promijenile rang | 79% |
| Prosječna konzistencija rangova: % mjera iz top 10 koje su ostale u top 10 | 76% |
| Prosječna konzistencija rangova: % mjera iz top 10 koje su ostale u top 20 | 82% |
| Prosječan broj promjena rangova u svim scenarijima | 6 |

*Izvor: Autor*

**Usporedba s PAPRIKA merodom i potvrda robustnosti izračuna težinskog faktora**

U svrhu dodatne validacije SYNERGISE+ metodološkog okvira i procjene njegove metodološke robusnosti, provedena je usporedna analiza s poznatom višekriterijskom metodom PAPRIKA (Potentially All Pairwise RanKings of all possible Alternatives), razvijenom u okviru softverskog alata 1000Minds. Ova metoda temelji se na sustavnom ispitivanju preferencija putem serije binarnih uparivanja između kriterija, gdje korisnik odabire preferirani ishod između dviju hipotetskih opcija koje se razlikuju u vrijednostima dvaju kriterija, dok su ostali kriteriji fiksirani. PAPRIKA metoda koristi kombinaciju teorije korisnosti i pristupa parcijalne agregacije kako bi rekonstruirala skup preferencija i iz njih izvela relativne težine svakog kriterija.

Usporedba s PAPRIKA metodom omogućila je testiranje valjanosti i stabilnosti rezultata dobivenih putem metode uparene usporedbe korištene u SYNERGISE+ modelu. Iako se obje metode temelje na izražavanju preferencija između kriterija, razlikuju se u strukturi pitanja i kognitivnom opterećenju koje zahtijevaju od ispitanika. SYNERGISE+ koristi metodu uparene usporedbe koja, u svojoj najjednostavnijoj formi, uključuje samo 19 pitanja za 12 kriterija, dok PAPRIKA, iako preciznija u teorijskom smislu, često generira znatno veći broj uparivanja, ovisno o složenosti problema i broju kriterija. Ova razlika čini SYNERGISE+ pogodnijim za primjenu u urbanim planerskim procesima u kojima sudjeluju dionici različitih razina tehničke stručnosti i dostupnog vremena.

**Tablica 3:** Usporedba simulacije elicitacije vrijednosti (težina) metodologijama PAPRIKA i SYNERGISE+.

| **Ime scenarija** | **Objašnjenje** | **Korelacija** | **Euklidska udaljenost** |
|---|---|---|---|
| Uravnoteženi scenarij | There is no preference, meaning all criteria are valued equally. | 0%[1] | 0.06 |
| Konvencionalni scenarij | Political acceptability and ROI are given maximum weight, followed by balanced social equity, institutional framework and technological dimension, overlooking the biodiversity and risk and vulnerability impact. | 93% | 0.06 |
| Održivi scenarij | Environmental goals and social wellbeing are paramount, regardless of the cost or necessary technology and legal changes to achieve them. | 97% | 0.04 |
| Extremni scenarij | Maximum possible differences in weights that the model can create. | 96% | 0.05 |

(1) Završni uravnoteženi scenarij jedini je koji zaobilazi ponderiranje na razini dimenzija te izravno dodjeljuje jednaku važnost svim kriterijima druge razine, pri čemu svaki dobiva 8,3 % (100/12). Time se osigurava ravnomjerna raspodjela važnosti. Iako se konačne težine podudaraju s onima iz PAPRIKA metode, ta se usklađenost postiže namjernim dizajnom, a ne kao rezultat izračunskog procesa.

*Izvor: Autor*

Rezultati usporedbe pokazali su visoku razinu korelacije između težina dodijeljenih kriterijima u oba modela. Konkretno, Spearmanov koeficijent korelacije između težina proizvedenih SYNERGISE+ metodom i onih dobivenih putem PAPRIKA metode iznosio je 0,88, što upućuje na snažnu pozitivnu povezanost u redoslijedu prioriteta. Osim toga, analiza konzistencije u rangiranju mjera pokazala je da se više od 70 % mjera koje su bile rangirane u gornjem kvartilu u jednom modelu pojavljuju i u istom kvartilu u drugom modelu. Ova konzistencija dodatno potvrđuje robusnost SYNERGISE+ modela, osobito u kontekstu scenarijskog planiranja gdje različite vrijednosne preferencije mogu dovesti do varijabilnosti rezultata.

Važno je istaknuti i praktične prednosti SYNERGISE+ metode u participativnim kontekstima. Dok je PAPRIKA metodološki izuzetno precizna i preporučljiva za manje skupine s visokim stupnjem angažiranosti i vremenskom dostupnošću, SYNERGISE+ metoda pokazala se učinkovitijom za veće skupine dionika, uključujući predstavnike lokalne samouprave, civilnog društva i stručnjake, zbog jednostavnosti uparivanja i kraćeg vremena potrebnog za ispunjavanje evaluacijskog upitnika.

Zaključno, usporedba s PAPRIKA metodom potvrđuje da SYNERGISE+ zadržava visoku razinu metodološke vjerodostojnosti i robusnosti, istovremeno nudeći operativne prednosti u participativnom odlučivanju u kontekstu lokalnog klimatskog i energetskog planiranja. Takav balans između analitičke preciznosti i praktične primjenjivosti čini SYNERGISE+ pogodnim alatom za integraciju u postojeće planerske procese gradova i općina diljem Europe i šire.

**Empirijska primjena na stvarnim klimatskim i energretskim planovima**

Empirijska primjena modela SYNERGISE+ provedena je na tri stvarna grada – Zagreb, Maribor i Litoměřice – te na dva hipotetska grada kako bi se testirala robusnost, fleksibilnost i praktična primjenjivost modela u različitim strateškim i kontekstualnim okruženjima.

1. STRUKTURA ODLUČIVANJA I RANGIRANJE MJERA

Rezultati pokazuju da su u svim gradovima ekonomski i institucionalni kriteriji imali najveću težinu u procesu odlučivanja. To se očitovalo u preferiranju mjera koje su financijski izvedive, politički prihvatljive i institucionalno podržane. Tehnički i društveni kriteriji, iako prepoznati kao važni u teoriji, u praksi su često marginalizirani, što ukazuje na potrebu za redefiniranjem pristupa održivom planiranju kako bi se osigurala ravnoteža među dimenzijama.

2. SINERGIJSKI POTENCIJAL MJERA

Od ukupno 174 mjere analizirane u okviru SECAP-a, njih 47 grupirano je u tematske klastere. Među njima, identificirana je 21 skupina mjera s izraženim sinergijskim potencijalom, što znači da istovremeno pridonose ublažavanju klimatskih promjena i prilagodbi na njihove učinke. Primjeri uključuju zelenu infrastrukturu, održivu mobilnost i pametna energetska rješenja. Korištenjem sinergijskih mjera moguće je ostvariti značajne uštede – u nekim slučajevima i do 5% ukupnih troškova implementacije – te povećati učinkovitost alokacije resursa.

3. ROBUSNOST I SCENARIJSKA ANALIZA

Primjenom različitih scenarija težina kriterija (npr. uravnoteženi, konvencionalni, održivi, tehnokratski i institucionalni scenarij) testirana je osjetljivost modela. SYNERGISE+ pokazao je visoku stabilnost rangiranja u većini scenarija, a posebno u onima gdje su ekonomski i institucionalni kriteriji dominantni. Usporedba s metodom PAPRIKA dodatno je potvrdila valjanost i učinkovitost korištene metode uparene usporedbe.

4. IDENTIFICIRANE SLABOSTI U POSTOJEĆIM SECAP-IMA

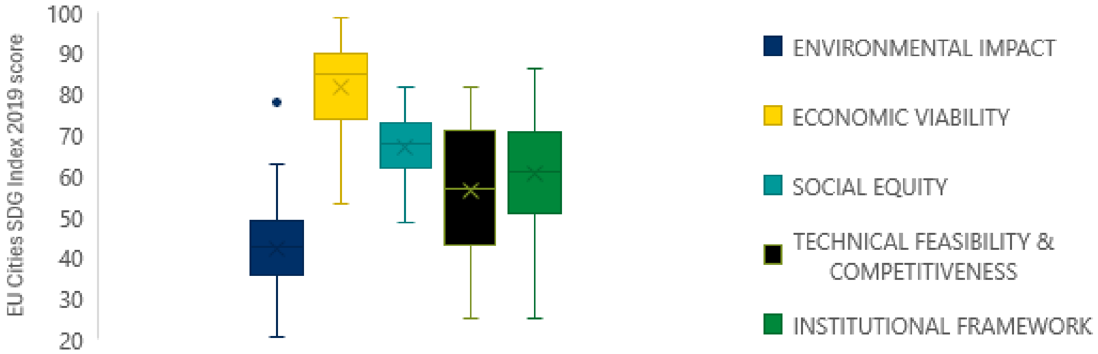
Analizom sadržaja postojećih SECAP-a utvrđeno je:

- Nedostatak eksplicitnog prepoznavanja sinergija među mjerama;
- Dominacija tehničkih i ekoloških mjera koje ne uzimaju u obzir društvene posljedice;
- Ograničena primjena participativnih metoda u odlučivanju;
- Nepotpuno mapiranje lokalnih prioriteta s globalnim SDG ciljevima.

Ovi nalazi ukazuju na potrebu za jačanjem metodoloških kapaciteta lokalnih vlasti te za razvojem pristupa koji istovremeno reflektiraju lokalni kontekst i omogućuju međunarodnu usporedivost.

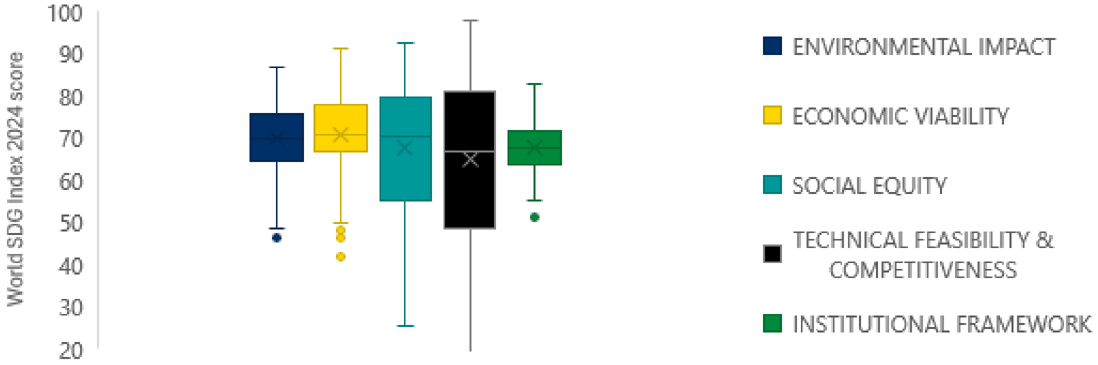
**Konceptualna integracija SYNERGISE+ okvira odlučivanja u UN-ove ciljeve održivog razvoja (SDG)**

Dodatno, model je primijenjen na UN-ove ciljeve održivog razvoja (SDG) na način da su se SDG ciljevi sagledali kroz pet SYNERGISE+ dimenzija. Usporedna analiza 45 europskih gradova (Prikaz 1) i 167 zemalja (Prikaz 2) pokazala je snažnu korelaciju između BDP-a i ukupne izvedbe u kontekstu ciljeva održivog razvoja. Ekonomija i tehnička izvedivost pokazale su se kao glavni prediktori SDG rezultata, dok su okolišni i društveni aspekti ostali u drugom planu. Takva strukturalna neravnoteža može dugoročno ugroziti koherentnost održivih politika ako se ne adresira kroz inkluzivnije i pravednije planiranje.




**Prikaz 1:** Trendovi uspješnosti po dimenzijama prema podacima o ciljevima održivog razvoja gradova za 2019. godinu

Izvor: Autor




**Prikaz 2:** Trendovi uspješnosti po dimenzijama prema podacima o ciljevima održivog razvoja zemalja za 2024. godinu

Izvor: Autor

## ZAKLJUČCI

Cilj ove disertacije je istražiti kako lokalne i regionalne vlasti mogu donositi informiranije odluke prilikom prioritizacije klimatskih mjera u okviru Planova održive energije i klimatskih promjena (SECAP). Razvojem i primjenom okvira za potporu odlučivanju SYNERGISE+, istraživanje je pokazalo da strukturirana metodologija temeljena na vrijednostima može znatno unaprijediti način na koji se klimatske mjere biraju, rangiraju i usklađuju s dugoročnim ciljevima.

Okvir SYNERGISE+ integrira pet dimenzija održivosti—ekološku, ekonomsku, društvenu, tehničku i institucionalnu—te omogućuje sudioničko određivanje važnosti kriterija od strane lokalnih dionika. Ovakav pristup omogućuje gradovima da prioritiziraju mjere ublažavanja i prilagodbe ne samo prema kratkoročnoj izvedivosti ili političkoj oportunosti, već u skladu s vlastitim vrijednostima i razvojnim prioritetima.

Kroz primjenu u trima europskim gradovima i dva modela scenarija, istraživanje potvrđuje glavnu hipotezu (H0): da strukturirani alat temeljen na vrijednostima, koji integrira obje klimatske dimenzije, može unaprijediti raspodjelu resursa otkrivanjem sinergija i sukoristi u planiranju urbane održivosti. Uz to, analiza potvrđuje nekoliko ključnih nalaza:

- Većina postojećih alata i planova ne evaluira sustavno mjere ublažavanja i prilagodbe zajedno (H1, H5).
- Sudioničke metode, poput usporednog uparivanja, učinkovito bilježe preferencije dionika bez kompromisa u jasnoći ili analitičkoj preciznosti (H2).

- Kada se lokalne preferencije eksplicitno uključe u modele bodovanja, prioritizacija mjera postaje bolje usklađena sa strateškim ciljevima grada (H3).
- U praksi, ekonomska i politička izvedivost često dominiraju procesima odlučivanja, dok su ekološki i društveni aspekti potcijenjeni (H6).

Iako je primarni fokus ovog istraživanja metodološki i usmjeren na odlučivanje, okvir SYNERGISE+ testiran je i u širem kontekstu održivog razvoja, kroz usklađivanje s Ciljevima održivog razvoja (SDG). Komparativna analiza provedena među 45 gradova EU i 167 država pokazuje da su dimenzije okvira SYNERGISE+ općenito kompatibilne s globalnim agendama održivosti, te mogu pomoći u prepoznavanju strukturnih neuravnoteženosti u provedbi ciljeva. Nalazi potvrđuju prevlast ekonomskih pokazatelja u ocjeni održivosti (H4), te ukazuju da čak i gradovi s visokim ukupnim ocjenama često daju prednost ekonomskoj održivosti nauštrb dugoročnih ekoloških ishoda.

Ključno je da ova disertacija ne nudi samo alat, već i filozofiju odlučivanja temeljenu na jasnoći, transparentnosti i kontekstualizaciji održivih izbora. Odlaskom od fragmentiranog planiranja temeljenog na kontrolnim listama prema integriranom vrednovanju koje uključuje dionike, SYNERGISE+ omogućuje bolje povezivanje političkih ambicija i provedbene stvarnosti. Gradovima se time omogućuje da prioritiziraju mjere koje su ne samo troškovno učinkovite, već i otporne, uključive i usmjerene prema budućnosti.

Zaključno, disertacija doprinosi teorijski i praktično području planiranja urbane održivosti. Pruža okvir koji se može replicirati i koji podržava donošenje informiranih odluka u uvjetima neizvjesnosti, te jača kapacitete lokalnih vlasti za provedbu mjera održivosti koje su koherentne, sinergijske i u skladu s vrijednostima zajednice.

## 5.1 Preporučene političke mjere

Na temelju nalaza ovog istraživanja, predlažu se sljedeće političke mjere s ciljem jačanja planiranja održivosti i poboljšanja prioritizacije klimatskih mjera u urbanim sredinama. Preporuke su grupirane u pet tematskih područja:

### I. Redefinirati okolišne ciljeve i pokazatelje

Za poticanje smislenijeg napretka prema ciljevima održivosti, osobito u visoko dohodovnim regijama, okolišni ciljevi moraju se preusmjeriti s mekih, ulazno orijentiranih pokazatelja na mjerljive ciljeve temeljene na ishodima. Istraživanje potvrđuje da ekonomski rezultati i dalje imaju najveći utjecaj na uspjeh u ostvarenju SDG-a (H4), često potiskujući dugoročne okolišne potrebe. Strategije ublažavanja i prilagodbe moraju se evaluirati zajedno, koristeći rigorozne metodološke okvire koji odražavaju stvarni utjecaj, a ne simboličke obveze.

**II. Ojačati tehničke i društvene kapacitete**
Uspjeh planova održivog djelovanja izravno je povezan s tehničkom spremnošću grada i društvenom uključivošću, što potvrđuju rezultati SYNERGISE+ analize i proširena SDG usporedba. Prioritet treba dati ulaganjima u zelene tehnologije, obrazovanje o klimatskim promjenama i programe društvenih inovacija, osobito u sredinama s nižim prihodima. Razvojna pomoć treba obuhvaćati ne samo financijsku potporu, već i jačanje institucionalnih i tehničkih kapaciteta za smanjenje dugoročnih nejednakosti u klimatskoj učinkovitosti.

**III. Poboljšati usklađenost lokalnog i nacionalnog planiranja**
Istraživanje ukazuje na nesklad između lokalnih prioriteta (npr. u SECAP-ima) i nacionalnih postignuća u provedbi SDG-a. Potrebno je uvesti redovite procjene SDG-a na razini gradova, temeljene na lokalno relevantnim kriterijima, kako bi se klimatske mjere bolje uskladile s nacionalnim i globalnim ciljevima. SYNERGISE+ nudi praktičnu metodologiju za ovu vrstu usklađivanja povezivanjem lokalnih mjera sa širim dimenzijama održivosti.

**IV. Institucionalizirati odlučivanje temeljeno na vrijednostima i sudjelovanju**
Vlade na svim razinama trebaju usvojiti strukturirane, transparentne alate za podršku odlučivanju—poput SYNERGISE+—kako bi prioritizirale mjere ne samo prema troškovima ili emisijama, već i u skladu s vrijednostima dionika i lokalnom izvedivošću. Metoda usporednog uparivanja testirana u ovom istraživanju predstavlja pojednostavljen, ali rigorozan pristup uključivanju dionika koji omogućuje gradovima da prilagode odluke svojem specifičnom kontekstu (H2, H3).

**V. Promicati integrirano i sinergijsko planiranje**
Na kraju, politički okviri trebaju sustavno razmatrati sinergije između mjera ublažavanja i prilagodbe, koje se često zanemaruju (H5). Integracija obje dimenzije u jedinstven model odlučivanja—kako pokazuje SYNERGISE+—može unaprijediti troškovnu učinkovitost, izbjeći dupliciranje mjera i potaknuti holističkije rezultate održivosti. Istraživanje pokazuje da sektorski integrirano planiranje, uz sudioničke alate, može pridonijeti koherentnijoj i otpornijoj provedbi politika.

Ovo istraživanje potvrđuje da su za postizanje održivih rezultata potrebni više od ekonomskog rasta. Potrebni su dobro strukturirani, participativni i transparentni procesi planiranja koji usklađuju mjere s dugoročnim okolišnim i društvenim ciljevima. Kako gradovi postavljaju sve ambicioznije klimatske ciljeve, usvajanje integriranih okvira za odlučivanje poput SYNERGISE+ bit će ključno za prevođenje visokih političkih obveza u konkretne i učinkovite lokalne mjere. Budući razvoj politika trebao bi se temeljiti na ovom okviru kako bi se unaprijedili koherentni, pravedni i učinkoviti putovi prema održivosti.

## 5.2 Ograničenja istraživanja

Iako ovo istraživanje donosi značajan metodološki i praktični doprinos planiranju urbane klimatske politike, potrebno je naglasiti određena ograničenja—prvenstveno vezana uz jedan specifičan segment studije. Kako je objašnjeno u poglavlju 4.6, okvir SYNERGISE+ pokazuje niz metodoloških prednosti, posebice u podršci sudioničkom i integriranom odlučivanju. Ipak, određena ograničenja, osobito ona povezana s analizom usklađenosti sa SDG-om, ostaju prisutna te su razjašnjena u nastavku radi pojašnjenja dosega i generalizabilnosti nalaza.

Prvo, samo dio studije koji validira usklađenost sa SDG-om—uspoređujući okvir SYNERGISE+ s podacima o postignućima SDG-a—oslanja se na presječne podatke iz 2019. godine. To uključuje metodološka ograničenja vezana uz prikupljanje podataka, moguće nedosljednosti i nedostatak ažuriranih ili dinamičnih pokazatelja. Budući da se radi o podacima iz jedne vremenske točke, mogućnost praćenja dugoročnih trendova u održivosti gradova je ograničena. Longitudinalni pristup pružio bi potpuniju sliku razvoja urbanih politika. Ipak, korišteni skup podataka predstavlja najopsežniji javno dostupan izvor podataka o SDG-u na razini gradova te je uloženo znatno nastojanje da se kritički evaluiraju i usklade relevantni SDG pokazatelji s dimenzijama SYNERGISE+ okvira. Važno je napomenuti da ovo ograničenje utječe isključivo na jedan segment analize i ne dovodi u pitanje valjanost šireg okvira SYNERGISE+ niti njegovih glavnih primjena.

Drugo, budući da su podaci o SDG-u bili dostupni isključivo za europske gradove, generalizabilnost analize usklađivanja sa SDG-om na ostale svjetske regije—posebno na zemlje s niskim i srednjim prihodima koje se suočavaju s drukčijim urbanim izazovima—ostaje ograničena. Buduća istraživanja trebala bi ispitati primjenjivost okvira SYNERGISE+ u širem geografskom i institucionalnom kontekstu.

Treće, iako klasifikacija gradova u četiri vrijednosna scenarija—balansirani, održivi, tehnokratski i konvencionalni—nudi korisne uvide u tipologije planiranja, gradovi koji ne potpadaju pod ove kategorije nisu detaljno analizirani. Buduće nadogradnje mogle bi identificirati hibridne ili prijelazne tipove gradova, čime bi se dodatno unaprijedila prilagodljivost i interpretativna snaga okvira.

Na kraju, ovo istraživanje je namjerno isključilo utjecaj vanjskih šokova, poput pandemije COVID-19 ili makroekonomskih poremećaja. Budući da su primarni podaci prikupljeni prije ili neposredno nakon tih događaja, njihov dugoročni strukturni utjecaj na održivost nije bio obuhvaćen. Potrebna su dodatna istraživanja kako bi se utvrdilo na koji način takvi šokovi mogu dugoročno promijeniti logiku prioritizacije i dinamiku donošenja odluka.

## Key Words

Urban Climate Planning, Sustainable Index, Mitigation and Adaptation Synergies, Decision-Making Methods, Sustainable Development Goals (SDGs)

## Ključne riječi

Urbano klimatsko planiranje, Indeks održivosti, Sinergije ublažavanja i prilagodbe, Metode donošenja odluka, Globalni ciljevi održivog razvoja (SDG)

# 1. Topic Introduction

### 1.1 Research Objectives and Hypotheses

Cities are at the forefront of addressing global sustainability and climate agenda, yet they must navigate multiple goals with limited resources and institutional capacity. Despite growing urgency, urban climate plans—particularly Sustainable Energy and Climate Action Plans (SECAPs) promoted under the EU Covenant of Mayors—often lack structured decision-support tools for systematically prioritising actions that maximise long-term value, co-benefits, and implementation feasibility (Balouktsi, 2019; Rivas, Urraca and Bertoldi, 2022). City planning[1], or strategic climate planning at the local level remains underdeveloped, particularly in the face of long-term risks and uncertainties. As Hutter (Hutter, 2007) notes in the context of flood risk management, local authorities often lack the strategic capacity to operationalise long-term resilience planning.

This research addresses that gap by developing and applying a structured, value-based Multi-Criteria Decision Analysis (MCDA) framework to guide the prioritisation of climate actions in cities. The framework is tailored to reflect local values, promote transparency, and support coherent planning across mitigation and adaptation domains.

The overarching research question guiding this dissertation is:

In what ways can multi-criteria decision-support tools enhance the ability of local governments to prioritise sustainable climate actions that are coherent, synergistic, and aligned with stakeholder values?

To answer this question, the research introduces the SYNERGISE+ framework—developed within the Horizon 2020 PROSPECT+ initiative—which provides a replicable and adaptable methodology for local planning. The tool integrates five dimensions of sustainability (environmental, economic, social, technical, and institutional), operationalised through twelve criteria. It applies a participatory pairwise comparison method to elicit stakeholder preferences and employs a compensatory scoring model to enable comparative evaluation of actions.

To ground the framework in real-world needs, the research draws on:

- A gap analysis of over 50 MCDA methods and 30 urban sustainability frameworks;
- Empirical data from the Covenant of Mayors database (11,000+ SECAPs);
- Insights from city participants in the Horizon 2020 PROSPECT and PROSPECT+ projects (100+ cities);

[1] **City Planning** – In this manuscript, used to denote strategic, cross-sectoral planning for sustainability in cities, including climate mitigation, adaptation, and socio-economic priorities. Distinct from “urban planning”, which traditionally focuses on spatial land use and zoning.

- Structured analysis of 174 SECAP actions, clustered into 47 bundles, with identified synergies across 21 of them.
- The research aims not to retrospectively rank cities, but to enable ex-ante prioritisation of local actions that yield the most significant combined sustainability benefits. This supports more strategic, consistent, and resource-efficient planning under budgetary and time constraints.

## Objectives of the Research

- Identify the gaps and limitations in existing urban sustainability planning frameworks, with a focus on decision-making processes for mitigation and adaptation.
- Understand the needs of cities in prioritising and implementing sustainable actions through empirical investigation of SECAPs and H2020 project outputs.
- Develop a comprehensive, value-based index of criteria relevant for both mitigation and adaptation planning.
- Construct a methodological framework for action prioritisation that incorporates stakeholder preferences, flags potential synergies, and improves investment decisions.
- Align the decision-support model with global sustainability objectives, including the SDGs, to assess broader policy relevance.

**Main Hypothesis**

H0: A structured, value-based decision-support tool that simultaneously evaluates mitigation and adaptation actions can enhance the prioritisation and resource allocation in sustainable urban planning by revealing and leveraging co-benefits and synergies.

**Supporting Hypotheses**

H1: Existing planning tools and indices rarely provide an integrated set of sustainability criteria for the joint evaluation of mitigation and adaptation measures.

H2: Pairwise comparison is an effective method for capturing stakeholder preferences in local climate planning, balancing simplicity and rigour in weight elicitation.

H3: Incorporating local stakeholder preferences into scoring models improves the alignment of prioritised actions with city-specific sustainability goals.

H4: Economic indicators continue to dominate sustainability performance assessments in SDG-related indices, overshadowing social and environmental considerations.

H5: Most SECAPs fail to systematically identify or integrate synergies between mitigation and adaptation measures.

H6: In practice, SECAP action prioritisation is more strongly shaped by financial and political feasibility than by environmental or social criteria.

**Table 1**: Secondary research hypotheses and testing methods.

| Independent variables – cause | Dependent variables – effect |
|---|---|
| H1: Existing planning tools and indices rarely provide an integrated set of sustainability criteria for the joint evaluation of mitigation and adaptation measures. | |
| Existing frameworks' key indicators and criteria. | Coverage of key dimensions in existing frameworks. |
| New comprehensive framework components. | Effectiveness of new framework in evaluating sustainable actions. |
| TESTING METHOD:<br>a) Literature review and gap analysis to document existing frameworks for sustainable actions in cities, focusing on key indicators and criteria used in each framework.<br>b) Comparing how well different frameworks cover the identified key dimensions and assessing the comprehensiveness and balance of each framework based on the identified components/factors. | |
| Perform correlation analysis, to compare the different indexes with the SYNERGISE+ index on 5 case studies (3 real and 2 test cities). | |
| H2: Pairwise comparison is an effective method for capturing stakeholder preferences in local sustainable planning, balancing simplicity and rigour in weight elicitation. | |
| Pairwise comparison method and PAPRIKA method (which uses Potentially All Pairwise RanKings of all possible alternatives) for both dimensions and criteria. | Time taken to get to result.<br>Ease of use - stakeholder satisfaction with the process.<br>Difference in preference elicitation of PAPRIKA and SYNERGISE+. |
| TESTING METHOD:<br>a) Comparison with Gold Standard – PAPRIKA method to compare the time taken, ease of use, and correlation of the results.<br>b) Sensitivity analysis – setting all possible solutions/answers to pairwise comparison and determining five realistic scenarios of stakeholder preferences to test all the pilot cities with. | |
| H3: Incorporating local stakeholder preferences into scoring models improves the alignment of prioritised actions with city-specific sustainability goals. | |
| Weighted scoring matrix in three actual and two model cities – reflecting five different scenarios of city preference. | Change in ranking of sustainable actions.<br>Alignment of actions with city goals. |

Different criteria weights.

TESTING METHOD:

Implementing the weighted scoring matrix in 7 case cities and test changes in results by comparing five different scenarios (different criteria weights) to test whether different preferences result in different ranking.

H4: Economic indicators continue to dominate sustainability performance assessments in SDG-related indices, overshadowing social and environmental considerations.

| | |
|---|---|
| City and country-level SDG scores by dimension. | Alignment with value-based scenarios; performance patterns. |

**TESTING METHOD:** Decomposition of 2019 SDG city data and 2024 SDG country data; scenario mapping and pattern comparison. Categorize SDG Cities' index into the original 5 dimensions and calculate contribution to each. Specifically, the steps are:

**Extraction of City Scores:** The city score is extracted from an existing sustainability index, such as the SDG Index score, for the **45 analysed cities and 167 countries**. The scores are categorized based on the index's predefined dimensions.

**Assignment to SYNERGISE+ Dimensions:** Each category from the existing index is mapped to the corresponding **SYNERGISE+ dimension**. If multiple categories correspond to a single dimension, an **average score** is calculated for that dimension.

**Normalization of Results:** The obtained scores are normalized to fit the **scale of the SYNERGISE+ model** (ranging from 0.5 to 1) **without introducing negative effects**.

**Contribution Analysis:** The relative contribution of each dimension is analysed, both **at the aggregate level** (across all 45 cities) and **individually** for each city.

**Scenario Comparison and Classification:** The obtained percentage distributions are **compared against the five predefined SYNERGISE+ scenarios**. Based on this comparison, each city is classified under the most appropriate scenario. Additionally, a general trend is identified, determining **the most common scenario across the analysed cities**.

This structured approach ensures that cities are systematically evaluated based on an established sustainability framework, while also enabling a meaningful comparison between existing sustainability scores and the SYNERGISE+ methodology.

| | |
|---|---|
| H5: Most SECAPs fail to systematically identify or integrate synergies between mitigation and adaptation measures. | |
| 3 SECAPs presence/absence of synergy links. | Number of synergistic actions; estimated co-benefit potential. |
| TESTING METHOD: | |
| **a)** Application of SYNERGISE+ to 3 SECAPs; comparison of synergy inclusion across cities. | |
| **b)** Quantitative Comparison and economic impact analysis: estimation of synergy-based cost-effectiveness. | |
| H6: In practice, SECAP action prioritisation is more strongly shaped by financial and political feasibility than by environmental or social criteria. | |
| Decision-makers' expressed preferences; financial and political feasibility scores. | Action prioritization rankings; scenario alignment. |
| TESTING METHOD: | |
| Value-based scenario modelling (Balanced, Sustainable, Conventional); analysis of rankings and their correlation with expert input in Maribor, Litoměřice, and Zagreb. | |

*Source: Author*

The secondary research for this study will include extensive literature review on the topic of decision-making applicable to local level. This research aims to identify current needs, challenges, and the state of decision-making in EU cities, as well as conceptualizing an appropriate method for a local decision-making framework. Primary research will be sourced from the Covenant of Mayors database of mitigation and adaptation plans database with over 8.000 cities worldwide uploading their SECAPs and the CDP-ICLEI 2023 Full Cities Dataset (CDP, 2023) with over 1.200 city respondents, and the framework will be tested via the Horizon 2020 PROSPECT project which had an outreach on 200+ European cities.

Additionally, the study applies the SYNERGISE+ framework to the 2024 World SDG Index (167 countries) (Sachs, Lafortune and Fuller, 2024) and the 2019 EU Cities SDG Index (45 cities) (Lafortune *et al.,* 2019). Regrettably, city-level data has not been collected since the 2019 prototype report. However, the observed trends provide sufficient information to fit each city and country into predetermined value approaches or scenarios which help draw conclusions about the motivators and drivers of urban development in the sample cities and countries. The four value approaches are: balanced, sustainable, technocratic and conventional scenario, which is hypothesized to be the most prevalent.

By integrating SDG scores into SYNERGISE+ dimensions and classifying cities and countries into five distinct scenarios the study reveals patterns in development strategies and their underlying motivators. These insights contribute to understanding why most cities prioritize economic outcomes and how countries balance technical, social, and environmental considerations.

To address these gaps, this research introduces the SYNERGISE+ framework, a flexible, value-driven, and qualitative multi-criteria decision analysis (MCDA) model designed to support local governments in prioritising sustainable energy and climate actions. Unlike conventional sustainability indices that benchmark external performance through fixed quantitative indicators, SYNERGISE+ functions as an internal decision-support tool, allowing cities to align priorities with local values, expert input, and resource constraints. It provides a holistic evaluation of mitigation and adaptation actions, integrating environmental, economic, social, technical, and institutional dimensions. By applying the methodology to three real SECAPs, this study demonstrates SYNERGISE+'s practical value in: (1) ranking actions based on feasibility and impact; (2) revealing trade-offs and co-benefits; (3) testing value-based scenarios to reflect decision-makers' preferences; and (4) identifying whether SECAP priorities are aligned with sustainability objectives or shaped by political or financial limitations.

By adopting both primary and secondary research approaches, this study aims to encompass cities of varying sizes, levels of development, and experience in sustainable planning and implementation.

## 1.2 Conceptual Framework and Research Design

The primary objective of this study is to develop a methodology that enhances decision-making for sustainable urban planning. This methodology integrates two fundamental approaches within a unified planning process:

- Mitigation – reducing energy consumption through efficiency measures.
- Adaptation – enhancing resilience to climate change impacts.

To achieve this, the methodology will outline a structured approach to prioritizing sustainable investments by:

- Identifying best practices in sustainable planning and value-based decision-making.
- Establishing a framework for eliciting individual preferences in decision-making.
- Developing an original criteria framework with two-level set of criteria that captures both direct and indirect benefits of sustainable actions, based on a comparative analysis of existing sustainable frameworks.
- Compiling a predefined catalogue of common mitigation and adaptation actions and their synergies.
- Constructing a scoring decision matrix to accommodate both qualitative and quantitative assessments.

- Identifying and leveraging synergies between actions to enhance cost-effectiveness.
- Performing analysis to test the robustness and practical applicability of the methodology.
- This approach serves a dual purpose: guiding sustainable action plan development and providing a systematic framework for monitoring, comparing and ranking investment options once a plan is approved.

## 1.3 Scientific Contribution and Expected Outputs

This research develops a methodology for prioritizing and selecting investment measures from local sustainable plans, integrating synergies between adaptation and mitigation actions in cities. By addressing existing gaps in sustainable urban planning, it provides a structured decision-support framework that enhances local governments' ability to implement sustainability actions efficiently. The contributions of this research span conceptual, empirical, and methodological advancements, integrating innovative elements to improve practical applicability.

### 1.3.1 Conceptual Contribution: Integrating Synergies into MCDA Decision-Making

A novel decision-making framework is introduced, incorporating an independent variable within the Multi-Criteria Decision Analysis (MCDA) model to account for synergies between adaptation and mitigation measures, even when their effects are not directly quantifiable. This "synergies potential" fosters integrated decision-making and aligns with EU and global sustainability goals, addressing a gap in conventional urban planning models that often treat adaptation and mitigation separately. The framework bridges theory and practice by integrating both objective indicators (e.g., energy savings, $CO_2$ reduction) and subjective factors (e.g., political feasibility, stakeholder engagement), ensuring a holistic and context-sensitive decision-making process.

Due to a misalignment between chosen measures and city priorities and the separation of mitigation and adaptation planning, results in undervaluation of co-benefits and suboptimal strategies. To address **SYNERGISE+**, a novel value-based Multi-Criteria Decision Analysis (MCDA) methodology was developed. **SYNERGISE+** introduces an original framework for sustainable urban decision-making, featuring:

- A comprehensive set of criteria encompassing both adaptation and mitigation.
- A value-based weight elicitation system.
- A structured methodology for prioritizing sustainable actions.
- A predefined catalogue of 67 common actions, highlighting potential synergies.
- Alignment with the EU Taxonomy for sustainability evaluation.

Unlike conventional assessments that compare cities retrospectively, **SYNERGISE+** is designed for ex-ante evaluations—supporting cities in selecting the most effective actions before implementation. This research examines the prioritization methodology within the **SYNERGISE+** framework, and it assesses synergy potential by calculating expected savings if mitigation and adaptation measures were implemented together. While this estimation remains approximate, indicating a 5% cost savings when synergistic mitigation and adaptation actions are implemented concurrently, the results highlight substantial potential benefits. Over 80% of actions in Maribor, Zagreb, and Litoměřice have synergy potential, with estimated preliminary savings of up to EUR 11.7 million (Litoměřice). These findings, although only indicative approximations, serve as a strong incentive for decision-makers to further refine planning strategies that maximize synergies and enhance cost-effectiveness.

### 1.3.2. Empirical Contribution: Setting the Basis for Evaluating the Impact of Synergies in Decision-Making

The research quantifies the impact of explicitly recognizing synergies in urban sustainability planning by:

- Establishing a theoretical linkage between adaptation and mitigation measures to reduce implementation costs and improve efficiency.
- Determining how synergy recognition alters the ranking and prioritization of SECAP measures, demonstrating its influence on decision-making outcomes.
- Analysing how different MCDA weight elicitation techniques (e.g., pairwise comparisons, local value considerations) affect decision outcomes in real city SECAP cases, ensuring local preferences are adequately represented.

This empirical validation ensures that the proposed methodology is not only conceptually sound but also practically applicable, offering a transparent and replicable approach for local governments.

### 1.3.3 Methodological Contribution: Enhancing Decision-Support Frameworks for Cities

To address limitations in existing urban sustainability planning tools, this research develops and applies SYNERGISE+, a structured yet accessible decision-support framework tailored to the needs of local governments preparing Sustainable Energy and Climate Action Plans (SECAPs). Its methodological contributions include:

- A dual-phase application: SYNERGISE+ is designed for use in both the planning phase—supporting the comparison and prioritisation of mitigation and adaptation measures based on stakeholder values, local objectives, and projected impacts—and the pre-implementation phase, where it informs resource allocation by identifying synergies and highlighting actions with greater cost-effectiveness and long-term benefits.

- A two-tiered criteria framework: The tool is built on a structured set of indicators grouped into strategic dimensions (e.g. long-term sustainability, alignment with policy goals) and operational dimensions (e.g. feasibility, institutional readiness, risk mitigation). This enables a transparent evaluation of trade-offs, tailored to each city's context and capacity.
- A participatory approach: Moving away from traditional top-down planning, the framework integrates stakeholder preferences through participatory weighting techniques, thereby increasing transparency, political legitimacy, and the likelihood of successful implementation.
- A comprehensive yet intuitive methodology: SYNERGISE+ incorporates a pre-defined library of 58 adaptation and 116 mitigation measures, supporting efficient selection and comparison of actions, particularly in municipalities with limited technical capacity.
- A qualitative impact matrix: The framework introduces a structured way to account for non-monetary co-benefits—such as social inclusion, health, and resilience—which are frequently undervalued or omitted in standard cost-benefit analyses.

In alignment with evolving EU policy frameworks—such as the EU Taxonomy—SYNERGISE+ moves beyond $CO_2$-centric metrics, enabling cities to assess their climate actions through the lens of resilience, social equity, and clean energy transition.

In the context of the MCDA general model outlined in Section 2.2.1, the following figure illustrates how these contributions advance local decision-making by integrating technical rigour with practical usability.

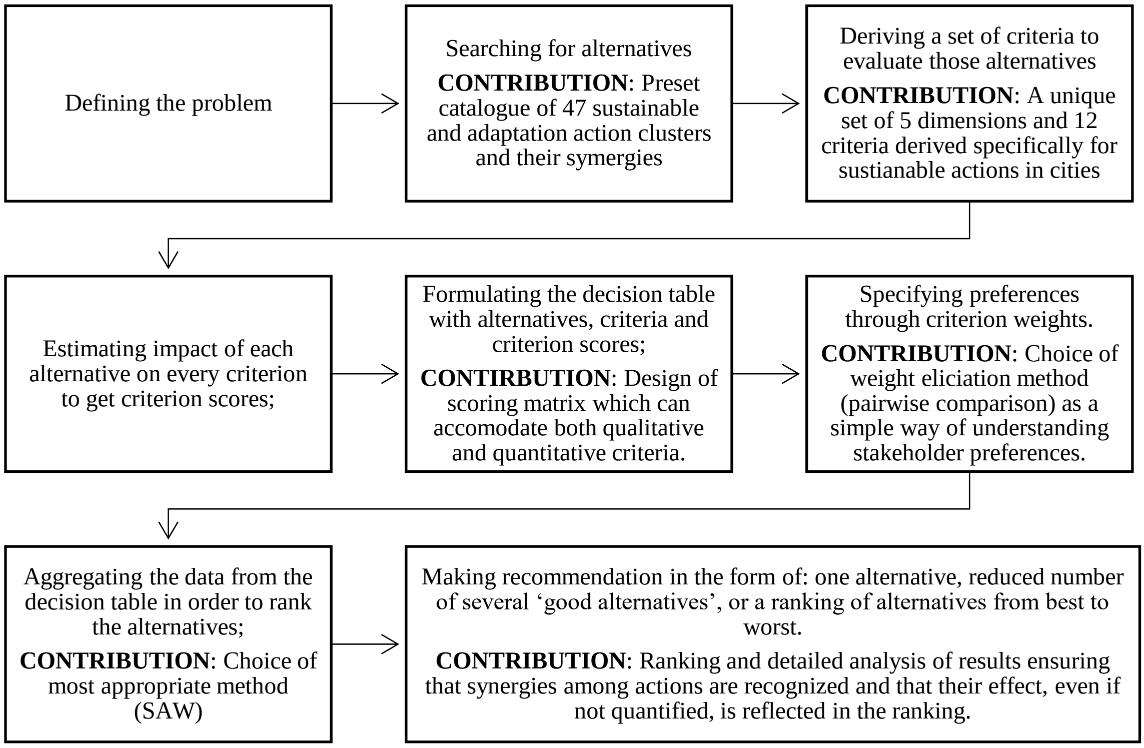



**Figure 1**: Research contribution in the context of the general MCDA model. Adapted from Wątróbski et al., 2019.

By integrating these conceptual, empirical, and methodological advancements into a single coherent framework, this research delivers a novel and practical decision-making methodology that enhances the effectiveness of SECAPs. The methodology is scientifically rigorous, yet accessible, ensuring its applicability for cities aiming to optimize sustainability investments while having an opportunity to leverage synergies between adaptation and mitigation actions.

## 1.4 Glossary of Main Terms and Abbreviations

**AHP** – *Analytic Hierarchy Process*. A structured MCDA technique that decomposes complex decisions into a hierarchy of sub-problems, each of which can be analysed independently. It uses pairwise comparisons and a scale of relative importance to derive criteria weights based on stakeholder judgements.

**City Planning** – Refers to strategic, cross-sectoral planning for sustainable development in cities, encompassing the prioritisation of climate mitigation and adaptation actions, integration of stakeholder preferences, and long-term systemic objectives. In this manuscript, city planning is value-based, involving participatory processes such as pairwise comparisons, and is typically carried out by local governments or municipal authorities. It differs from traditional urban planning by not being limited to spatial or zoning concerns.

**Co-benefits** – Secondary positive outcomes generated by climate actions, such as improved health, air quality, biodiversity, or social cohesion. These benefits are not the primary goal but reinforce the overall value of interventions.

**Local Government / Municipal Planning** – Refers to the institutional and administrative planning processes at the municipal or city level. These actors are responsible for implementing city planning strategies and SECAPs in line with national and international sustainability goals.

**MCDA** – *Multi-Criteria Decision Analysis*. A methodological framework for evaluating and comparing policy or investment options based on multiple, often conflicting criteria. It enables structured, transparent, and value-informed decision-making, especially when stakeholder preferences are incorporated.

**Normalisation** – A technique used in MCDA to convert diverse indicator values to a common scale, allowing meaningful comparison and aggregation across criteria measured in different units or magnitudes.

**Objective Weighting** – A method of assigning weights based on mathematical characteristics of the data itself (e.g. entropy or standard deviation), without incorporating stakeholder input.

**SAW** – *Simple Additive Weighting*. An MCDA aggregation method where normalised criterion scores are multiplied by their corresponding weights and summed, producing a single performance score for each alternative.

**SDG** – *Sustainable Development Goals*. A set of 17 global goals adopted by all United Nations Member States as part of the 2030 Agenda for Sustainable Development.

**SECAP** – *Sustainable Energy and Climate Action Plan*. A strategic document promoted by the Covenant of Mayors that guides cities and municipalities in implementing measures for climate mitigation, adaptation, and energy sustainability.

**Subjective Weighting** – A weighting method based on stakeholder opinions, expert judgement, or participatory elicitation, often implemented through pairwise comparisons or ranking exercises.

**Synergies** – In this study, synergies refer to the enhanced results that emerge when climate mitigation and adaptation actions are planned jointly, generating added value or avoiding trade-offs. These are distinct from co-benefits in being intentionally designed.

**Urban Planning** – A planning domain traditionally focused on spatial layout, land use, zoning regulations, and infrastructure development. Urban planning is more narrowly defined than city planning and does not inherently integrate broader sustainability governance or stakeholder-based decision frameworks.

**USIFs** – *Urban Sustainability Indicator Frameworks*. USIFs. Existing indicator systems used to evaluate urban sustainability across various dimensions (e.g. environmental, economic, social, governance). In this manuscript, USIFs are screened to understand which impact dimensions are typically prioritised in current city sustainability frameworks. They serve as a reference point but are not applied or extended within the SYNERGISE+ model, which instead introduces a value-based framework focusing on impacts rather than quantitative indicators.

**Value-Based Planning** – A planning and evaluation approach that explicitly incorporates stakeholder values, preferences, and priorities into decision-making processes. In this research, it is implemented via MCDA techniques, including pairwise comparisons and weighting.

# 2. Literature Review

Decision-making in realm of sustainable development involves analysing choices that can have long-term impacts on the environment and society, understanding the costs and benefits of different alternatives and evaluating the uncertainties. As such a complex area, it is a cross-discipline studied by economists, managers, political scientists, statisticians, but also by psychologists, neuroscientists, philosophers, and social scientists as decision-making is foremost a cognitive process. Such a multifaceted topic can be viewed from many perspectives and, as shown in Figure 2, **this research focuses mainly on prescriptive, active decision making techniques in the field of sustainable development in cities, concretely for mitigation and adaptation measures present in Sustainable Action and Climate Action Plans (SECAPs)**.

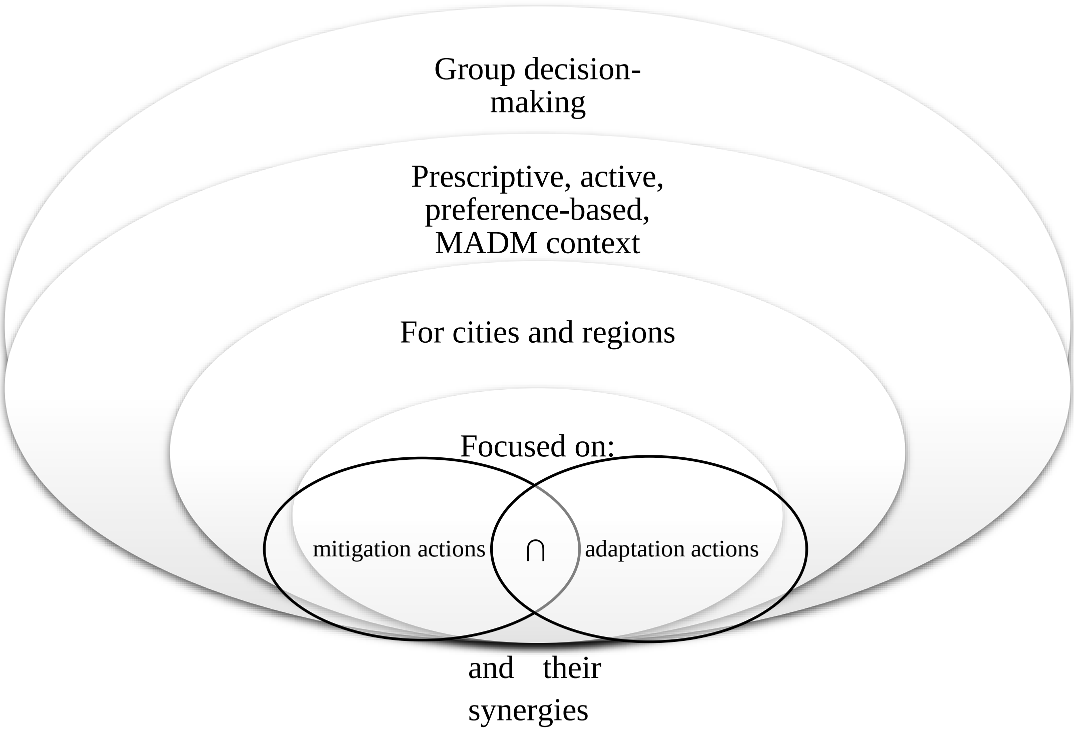



Figure 2: Research focus.
*Source: Author*

Prescriptive means that it studies what people should do to achieve a better outcome, instead of what they actually do (descriptive), and specifically high-stake, more complex active decisions involving multiple stakeholders and objectives (Network for Business Sustainability, 2012a).

Due to the expansive nature of this topic, the literature review is divided into different sections. First, the context of cities - their opportunities, challenges and needs are explained. Additional, origins of sustainability are covered, to understand the importance of decision-making as well as the complexity of goals to be achieved under the overarching topic of sustainability. Second, the state of the art of decision-making methods applicable to sustainable development are discussed, namely (1) cost-benefit analysis (CBA); and (2) applied information economics (AIE). Third, as MCDA was recognized as the prevalent method for sustainable urban decision-making, a section is devoted to choosing a proper MCDA method and their application.

33 MCDA techniques are systematically reviewed to find an appropriate methodology for local sustainable planning and to incorporate criteria for planning both mitigation and adaptation. Finally, a summary of literature review is given highlighting the current gaps in literature regarding the discussed topic of sustainable decision-making in cities.

## 2.1 Cities and Sustainable Development

### 2.1.1 The Role of Cities in Sustainability and Their Challenges

Cities play a pivotal role in achieving sustainability goals, as they are well-positioned to implement measures that directly engage citizens, consumers, and local energy communities. Cities, as economic hubs and major contributors to greenhouse gas (GHG) emissions, play a central role in global sustainability efforts. According to the United Nations (2018), while covering just 2% of the Earth's surface, cities produce 60% of global GHG emissions. By 2050, 68% of the global population is expected to reside in urban areas, up from 55% in 2022. The EU's *State of Cities and Regions* report (European Committee of the Regions, 2022) warns that without cities' commitment, 105 of the 169 SDG targets, including poverty reduction and infrastructure greening, will not be met by 2030.

However, they often face barriers such as data limitations, siloed planning, and restricted financial and technical capacities. Additionally, adaptation and mitigation measures are frequently planned in isolation rather than as part of a cohesive urban development strategy, unless legally mandated. To overcome these challenges, it is essential to streamline the planning process and integrate mitigation and adaptation within a unified framework that enables cities to analyse and compare diverse measures effectively.

Cities and other local authorities are especially important in Europe, where there are around 87.000 municipal level governments, including cities (OECD, 2021). However, only a small number of those local authorities takes part in most prominent European organisations tackling the clean energy transition. For example, in 2023 the abovementioned Covenant of Mayors had 11.812 signatories, Energy Cities a thousand city members and European Energy Award 1.872 signatories. This implies a vast space for research and impact in reaching out to more local authorities and including their opinions.

While offering significant potential for enhanced quality of life and effective responses to health, societal, and environmental challenges, cities also confront complex obstacles. They function as dynamic organisms, often without clear boundaries – they encompass more than just physical infrastructure, serving as hubs that shape the quality of life and growth trajectories for extensive populations and surrounding areas. The transition from traditional, defined urban planning to more expansive strategies that consider broader communities (such as integrating commuters in city planning, not just residents, or acknowledging that a city's natural resources are impacted by a larger ecosystem extending beyond its borders) necessitates a revision in decision-making criteria. This shift reflects an understanding that urban planning must account for the interconnected nature of cities and their wider influence (S. Cajot *et al.*, 2017).

The world is falling short of achieving the UN Sustainable Development Goals (SDGs) (Sachs, Lafortune and Fuller, 2024), and lack of budget is often still cited as the main hurdle to realising them, despite the existence of the Cohesion Fund and many other means of financing goals. Another significant reason for this shortfall is the flawed valuation within existing development models, where economic growth is prioritized over environmental and social well-being (Spaiser *et al.*, 2017). Conventional SDG metrics often obscure the underlying drivers of progress, resulting in policies that may be economically successful but unsustainable in the long term. Current sustainable development indicators either lack focus—overemphasizing either mitigation or adaptation—or are overly broad, failing to capture the interplay between economic, environmental, and social factors.

Although the estimates of Climate Finance Initiative from 2021 confirm that the existing global finance should increase to $4.35 trillion annually by 2030 to meet the set objectives, which is almost a hundred and fifty times more that the current spending estimated to be $632 billion per year (Buchner *et al.*, 2021a, p. 2), the current budget is still a lot of means to tackle climate change. One of the central questions of this research is whether there is a better way to utilize the budget for common mitigation and adaptation measures? The Climate Finance Initiative (Buchner *et al.*, 2021b) further concludes that in both 2019 and 2020 most finance was raised as debt, while almost 100 percent of that debt was provided by public institutions. That is a beneficial motivator for cities to turn this spending around from debt to investment, through adapting to climate change and anticipating future climate risks. Such a transition would ensure that the money spent reaps most benefits. Unfortunately, this is not yet the case, since the same report from the Climate Finance Initiative shows 90 percent of total climate finance was spent on mitigation measures, and that projects with dual uses of both adaptation and mitigation accounted for 2 percent.

Another challenge in implementing sustainable actions in cities is the so-called silo-mentality, an inward-oriented approach, where traditionally cities have a closed mindset and are reluctant to share information or collaborate among departments. To deal with rapid urbanization and break this silos mentality Bai et al. (2016) conclude that an advanced systems approach is needed. They recognize 6 main barriers to a systems approach are (1) Institutional evolution/behaviour; (2) Failure to recognize the systemic nature of cities; (3) Inadequacy of mental models; (4) Lack of incentives; (5) Path-dependency and lock-in; and (6) Inadequate decision-support systems. They continue to conclude that the latter two barriers can both be overcome by better planning and decision-making with a much wider scientific deliberation about metrics available or chosen as indicators for sustainable development and the data collected on the basis of these choices, and a better capacity for spatial and statistical disaggregation of urban data. To overcome this, expertise on urban areas should be integrative and informed, incorporating maximization of synergies and minimization of trade-offs across sectors. Decision-making while respecting the multisystem of cities requires a wide variety of experts but should simultaneously be comprehensible for policymakers to understand, adopt, and further promote.

As long as energy or environment related problems are considered someone else's problem, the compliance to the needed change in behaviour will be diminished. Neuroscience has new ways of proving that individuals tend to lose interest and show less compliance when they are not individually included in the decision-making process. Conversely, involvement in the decision-making process is associated with a stronger sense of shared ownership over positive outcomes, which, in turn, increases the likelihood of active participation in the implementation of required actions. El Zein et al. (2022) demonstrated that sharing responsibility with others reduces agency and provides opportunities to flexibly claim credit for positive outcomes.

There is extensive evidence that citizen participation in environmental decision-making leads to improved policy outcomes. Centofanti and Murugesan (2022) provide a comparative overview of leadership and public involvement in environmental initiatives, showing that citizen participation positively influences the achievement of sustainability goals, whereas leader endorsement alone has limited impact. Bardhan and Mookherjee (2006) demonstrate that active public involvement in project selection contributes to more successful implementation, while Matsusaka (2005) shows that direct democracy mechanisms, such as ballot initiatives, enhance government performance by encouraging greater civic engagement and accountability. Similarly, the Calotte Academy (The Norwegian Barents Secretariat, 2016) emphasises the role of open dialogue and interdisciplinary collaboration in tackling regional sustainability challenges. It highlights how participatory forums can effectively bridge the gap between scientific knowledge and policy implementation, particularly in complex, multi-level governance contexts.

As cities transition from reactive responses to proactive sustainability leadership, they must anticipate risks, incorporate uncertainties, and move beyond the traditional focus on economic efficiency. Historically, urban planning has prioritized immediate financial costs and returns, neglecting broader benefits such as resilience, public health, and long-term economic stability. As sustainability thinking evolves, there is a growing recognition that indirect benefits—such as energy independence and health improvements—can significantly impact long-term planning and investment strategies. This shift necessitates smarter decision-making tools that ensure sustainable action plans prioritize the most impactful measures within available budgets.

Strategic urban planning, particularly for long-term climate resilience, requires not only technical foresight but also institutional learning and adaptive governance mechanisms—a challenge well documented in local flood risk management contexts (Hutter, 2007).

### 2.1.2 Untapped Synergy Potential in Local Climate Actions

Along with establishing binding targets, which have demonstrated effectiveness in achieving specific goals, there is a pressing need for cities to optimize their limited financial and human resources in decision-making processes. This can be done through a holistic planning process and taking advantage of action synergies and co-benefits.

Urban planning is a complex challenge requiring an integrated approach to climate mitigation and adaptation, through adopting a shift from a confined approach to a broader, interconnected perspective, integrating commuter needs and ecosystem dependencies (S. Cajot *et al.*, 2017). This requires balancing environmental, social, and economic priorities while addressing climate risks through coordinated mitigation and adaptation strategies. Since the 1990s, this need for both adaptation and mitigation in tackling climate change has been widely acknowledged, but their synergies were not explored until the fourth IPCC Assessment Report (Klein *et al.*, 2007). Synergies, defined as the interaction where combined adaptation and mitigation effects exceed the sum of their separate impacts, are increasingly recognized alongside co-benefits (Klein *et al.*, 2007; Landauer, Juhola and Söderholm, 2015; Nordic Council of Ministers, 2017; S. Cajot *et al.*, 2017; Sharifi, 2021).

However, the exploration of these synergies remains limited, especially in economic approaches, which were covered in only 4 out of 56 papers reviewed (Sharifi, 2021). It often involves reducing energy and water use and enhancing climate resilience through greening initiatives (Nordic Council of Ministers, 2017), which requires innovative planning and cross-sectoral collaboration, both of which are currently lacking in many cities (Landauer, Juhola and Söderholm, 2015).

Sustainable Energy and Climate Action Plans (SECAPs) have become a widely adopted tool for urban adaptation to climate change among European cities, and recently globally, offering structured strategies to meet both mitigation and adaptation goals. However, many SECAPs exhibit a disconnect between mitigation and adaptation planning, treating them as separate domains rather than as interdependent strategies that can generate synergies. Despite widespread recognition of the need for integrated sustainability planning, the practical implementation of synergistic actions remains limited. Even among frontrunner cities with advanced climate strategies, efforts to systematically assess and leverage synergies are rare. Author's analysis of the Covenant of Mayors - Europe MyCovenant (Baldi *et al.*, 2023) reporting platform shows that adaptation was largely absent from urban planning before it became a mandatory objective in 2019, and even aftegrward, the integration of synergies remains underexplored.

**Table 2**: Covenant of Mayors signatories' plans including adaptation goals.

| Year | Total plans submitted | Plans with adaptation goals (%) |
|---|---|---|
| 2016 | 625 | 55 (9%) |
| 2017 | 356 | 80 (22%) |
| 2018 | 210 | 130 (62%) |
| 2019 | 238 | 224 (94%) |

*Source: Author's analysis of Covenant of Mayors database* (Baldi *et al.*, 2023)

This challenge is not confined to Europe; the 2022 City Questionnaire (CDP and ICLEI, 2023), which surveyed over 1000 urban sustainability plans, found that only 58 explicitly assessed synergies, with just 9 EU cities demonstrating an integrated approach. Given that the survey represents cities with the capacity and knowledge to engage in structured planning, this suggests that the majority of municipalities globally lack the resources or methodological support needed to implement truly integrated sustainability strategies.

Cities, particularly those with limited financial and technical resources, struggle to adopt sophisticated planning methods that can account for these synergies while balancing competing priorities of multiple stakeholders. Cuoghi and Leoneti (2019) highlight the importance of group multi-criteria decision analysis (MCDA) methods in structuring complex policy decisions, particularly in cases where multiple actors with divergent objectives must reach a consensus. Their findings underscore the necessity of integrating transparent, participatory frameworks to align urban sustainability goals with stakeholder expectations. Cowell and Webb (2024) corroborate this finding, however, their recent meta review of local energy plans concludes that analyses of political dynamics, exclusions, and governance constraints remain rare.

This gap highlights the need for decision-support tools that integrate mitigation and adaptation actions, and recognize their potential synergies.

### 2.1.3 Cities and the Evolution of the Sustainable Development Agenda

The analysis focuses on the United Nations (UN) Sustainable Development Goals (SDGs), a set of 17 comprehensive goals tracking national progress on 69 targets through 247 indicators, 92 of which are environment-related (Leboeuf, 2018).

The beginnings of monitoring sustainable development can be traced to the 1972 UN Conference on the Human Environment, leading to the creation of the United Nations Environment Programme (2023). This program was established to monitor the state of the environment, inform policy-making with scientific data, and coordinate responses to global environmental challenges. The term "sustainable development" was later defined in the 1987 report "Our Common Future" by the Brundtland Commission of the United Nations (Cocklin and Moon, 2020).  In 2006, the United Nations published the Principles for Responsible Investment (PRI) Report, coining the term ESG to encourage investors and business leaders to integrate environmental, social, and governance criteria into their operations. The ratification of the Paris Climate Agreement in 2015 further solidified the importance of ESG with the establishment of the UN Sustainable Development Goals (SDGs), which are now the most widely used indicators for national sustainable progress (Hariram *et al.*, 2023).

The concept of sustainable development in the mentioned reports emphasized the need for integrating environmental, social, and economic dimensions in decision-making. These principles were later operationalized through frameworks like the Triple Bottom Line (TBL), which highlighted the interdependence of 'people, planet, and profit' (Elkington, 1994; Hammer and Pivo, 2017), the incorporation of ESG (environment, social, and governance) factors into investment portfolios, and the Global Reporting Initiative (GRI) which established global principles for sustainable accounting. The triple bottom line, introduced by John Elkington (1994), shifted the focus from a singular bottom-line approach to one that includes social and environmental impacts alongside economic performance. In 2006, the United Nations published the Principles for Responsible Investment (PRI) Report, coining the term ESG to encourage investors and business leaders to integrate environmental, social, and governance criteria into their operations. The ratification of the Paris Climate Agreement in 2015 further solidified the importance of ESG with the establishment of the UN Sustainable Development Goals (SDGs), which are now the most widely used indicators for national sustainable progress. Recently, new concepts such as *sustainalism*, which centers on social well-being, have emerged (Hariram *et al.*, 2023).

Meta-analyses examining the origins of the triple bottom line and sustainable economic development theory conclude that, although central to economic development, the three pillars are not strictly defined or separated (Purvis, Mao and Robinson, 2019). Furthermore, while the TBL approach is familiar and favored by many, it has rarely been systematically applied and lacks uniformity (Hammer and Pivo, 2017). This underscores the importance of comprehensive indicators in the public sector for tracking sustainable progress of specific criteria. These criteria are often categorized into three or four main dimensions to form a framework, called Urban sustainability indicator frameworks (USIFs): environmental, economic, social, and sometimes institutional. Michalina et al. (2021) reviewed 50 USIFs and identified 50 most used criteria which enable sustainability to be clearly measured and assessed. The Routledge Handbook of Sustainability Indicators (Joss and Rydin, 2018) suggests that due to the diverse nature of sustainable urban development across different cities and regions, it is impractical to establish uniform global standards. Instead, the focus should be on procedural dimensions, encouraging 'good practice' in institutional, organizational, and social processes. This approach facilitates knowledge transfer and learning across various settings, enabling effective engagement in sustainable development, particularly where governance is limited. Despite differences in the applicability, sustainability dimensions, and methods of measurement, there are common aspects that should be respected when forming an indicator, such as validity, international comparability, consistency over time, and it should be linked with current policies or emerging issues (Dizdaroglu, 2017). With that in mind, the existing SDG indicators will be analysed to form a more comprehensive understanding of their results. Kant and Wu (Kant and Wu, 2012) discuss clear financial and broader economic and ecological limits to countries adopting adaptation efforts and argue that achieving a balance between mitigation and adaptation actions is crucial for achieving climate goals.

Another reason it is important to observe sustainable actions more closely is that adaptation actions, or the ones directly helping respond to climate change, are often falling behind mitigation and this lag is being masked by the common umbrella of sustainable actions. The author's analysis of the Covenant of Mayors - Europe MyCovenant reporting platform (CoM, n.d.) shows that before adaptation became a mandatory objective, very few cities included it in their planning. Even after 2019, when all signatories formally recognized adaptation goals, the focus on synergies between adaptation and mitigation remains underexplored. This challenge is not confined to Europe. The 2022 City Questionnaire (CDP and ICLEI, 2023) including more than 1000 urban sustainable plans, aimed at helping cities track climate strategies, shows that of the 896 plans, only 58 assessed synergies, and just 9 of those were EU cities with integrated mitigation and adaptation plans. Additionally, observation of Climate Financing showed that in the beginning of sustainable financing, 96% of climate finance was used for mitigation measures as opposed to adaptation (Elkington, 1994; Hammer and Pivo, 2017). Literature strongly supports the idea that both developed and developing countries need innovative, cross-sectoral, multi-criteria tools and methodology for both local synergistic planning of (Landauer, Juhola and Söderholm, 2015), and national reporting on sustainable actions (Martín-Ortega *et al.*, 2024).

Recent analyses of the SDGs indicate that their existence has not significantly influenced sustainable trends, with countries largely continuing their business as usual (Ordonez-Ponce, 2023). Furthermore, economic growth has been found to hinder environmental goals (Spaiser *et al.*, 2017). Research on SDGs is predominantly focused on developed countries (Mishra *et al.*, 2024), which are already performing well in achieving their goals, while lagging countries, often poorer, have the most missing data (Dang and Serajuddin, 2020).

### 2.1.4 Enabling Conditions for Effective Local Sustainability Planning

Effective urban sustainability planning requires integrating key decision-making aspects: (1) engaging stakeholders; (2) securing political support; (3) aligning criteria with national strategies and goals; and (4) leveraging synergies between adaptation, mitigation, and other policy priorities, such as the Efficiency First principle in the European context.

Despite extensive planning efforts, cities frequently struggle with implementation due to insufficient political backing, inadequate citizen participation, and suboptimal decision-making frameworks. These challenges often arise from the absence of structured, methodological approaches that translate plans into actionable strategies. The complexity of urban sustainability necessitates participatory planning tools that facilitate transparent and effective decision-making.

A recent global study (Petzold *et al.*, 2023) identified a significant disconnect between planning and implementation actors, where local and sub-national governments dominate planning while households and individuals are the primary implementers. Similarly, Giannakidis et al. (2018) highlighted that many energy-related measures remain unrealized due to insufficient political support. To bridge this gap, Marinakis et al. (2017) emphasize the need for participatory approaches combined with analytical decision-making tools in Sustainable Energy Action Plans, enabling citizens to express preferences and enhance implementation potential.

Citizen participation has been shown to improve project outcomes in decentralized governance. Research demonstrates that direct democracy mechanisms, such as voting on specific projects (Matsusaka, 2005), and active involvement in project selection (Bardhan, P., Mookherjee, 2006), lead to better implementation and increased willingness to share costs (Centofanti and Murugesan, 2022). However, stakeholder involvement is resource-intensive, making it challenging for cities with limited capacities to conduct inclusive planning. De Boer & Zuidema (2015) advocate for an area-based approach, linking local energy initiatives to physical and socio-economic contexts to enhance feasibility.

An analysis of the 2022 City Questionnaire (CDP & ICLEI, 2023), covering over 1,000 urban sustainability plans, found that 64% were completed without external consultants, with integrated plans (combining adaptation and mitigation) involving the least consultant engagement. Specifically, 41% of adaptation plans and 43% of mitigation plans were authored by consultants globally, while integrated plans had the lowest consultant involvement (32% globally, 31% in the EU). These figures indicate that most cities rely on internal resources, reinforcing the need for accessible decision-support tools when specialized expertise is unavailable. Notably, as the survey represents frontrunner cities with existing planning capacities, the global need for simplified planning tools is likely even greater.

Even with participatory planning tools, a key challenge in MCDA is the conversion of qualitative criteria into quantitative data, introducing potential biases (Network for Business Sustainability, 2012b). Statistical algorithms often outperform human judgment (Grove and Meehl, 1996a), yet decision-makers frequently resist them due to measurement aversion and the uniqueness fallacy—the belief that their situation is too distinct for standardized approaches (Hubbard, 2014a). Moreover, overly complex models can lead to decision fatigue, discouraging critical evaluation and resulting in suboptimal choices (Hahn and Tetlock, 2008a; Hubbard, 2014a). Thus, balanced approaches are necessary to avoid both oversimplification and excessive complexity in decision-making.

Research underscores the importance of linking planning with implementation through systematic decision-support tools. While existing methodologies recognize stakeholder involvement as beneficial, the effort required must be weighed against available resources. MCDA, when structured effectively, provides a means to integrate diverse preferences while ensuring transparency and prioritization in sustainable urban planning (Carli, Dotoli and Pellegrino, 2018).

## 2.2 Decision-Making in Urban Sustainability

This section presents an overview of prevalent decision-making methods commonly employed in various fields and applicable to sustainable actions, including (1) Multiple Criteria Decision Analysis (MCDA (Zavadskas and Turskis, 2011)); (2) Cost-Benefit Analysis (CBA) (Alaoui and Penta, 2022); and (3) Applied Information Economics (Hubbard, 2014a) (Table 3).

First, multiple criteria decision analysis (MCDA), is covered since it is a prevalent model for decision-making including many different projects to be compared, as well as different variables to compare them by. MCDA is one general method with different available techniques to apply this method.

**Table 4** presents a summary outlining their approaches, underlying principles, as well as the benefits and downsides associated with each method. Presenting this information is the first step towards understanding the gaps in current models and how each model corresponds with the topic of this research – optimizing sustainability in cities and balancing their energy, climate and resilience goals.

Finally, biases to be avoided, or at least be aware of, are presented to help combat subjectivity or pure false logic in participative decision-making.

**Table 3**: Overview of Decision-Making Methods.

| Method | Approach | Underlying Principles | Key Features | Downsides |
|---|---|---|---|---|
| **MCDA** - Multiple Criteria Decision Analysis (Zavadskas and Turskis, 2011) | Systematic consideration of multiple criteria for comparing and ranking alternatives based on multiple criteria or attributes | Explicitly consider multiple criteria with different weights; assess trade-offs. | Comprehensive evaluation of alternatives. Transparency in decision-making. Facilitates trade-off analysis. Allows for the consideration of multiple criteria simultaneously. Uses various weighting and ranking techniques. Varied application areas. | Requires substantial data and input. Complex decision framework may be time-consuming. Subjective criteria weighting can introduce bias and add further ambiguity to the solutions. |
| **CBA** - Cost-Benefit Analysis (Alaoui and Penta, 2022) | A method for evaluating decisions by comparing the costs and benefits through monetizing the net present-value or benefit-cost ratio of alternative courses of action. | Economic efficiency, maximizing societal welfare through positive net benefits. | Well-established and widely used. Focuses on economic efficiency. Monetizes outcomes for comparison and utilizes net present value or benefit-cost ratio for decision-making. Typically used for government policy and project evaluations. | Difficulty in valuing non-monetary factors. Ignores distributional impacts. Sensitive to discount rate and assumptions. |
| **AIE** - Applied Information Economics (Hubbard, 2014a) | A decision analysis method that assesses the value of information and quantifies uncertainties to make decisions that maximize expected value. | Managing risks, quantifying uncertainties, maximizing expected return on investment. | Emphasizes risk management. Focuses on information value and risk analysis through incorporating probability distributions and sensitivity analysis. Accounts for uncertainty and variability. Helps in choosing actions that maximize the expected ROI. | Requires expertise in risk assessment and information economics. Complexity in handling probabilistic information. May not fully capture qualitative factors. |

*Source: Author*

### 2.2.1 Multi-Criteria Decision Analysis (MCDA)

This study focuses on MCDA methodologies tailored for sustainable planning, particularly in the context of SECAPs. This chapter explains general principles behind MCDA to understand different available methodologies. A systematic review (Network for Business Sustainability, 2012b) of 207 sources on sustainable decision-making highlights that MCDA is one of the two key methods that involve stakeholder input and collaboration. The other one is Structured Decision Making (SDM), with the main difference being that MCDA uses mathematical models and algorithms to rank solutions, distinguishing it from SDM. Despite being time-consuming and requiring expertise, these methods are effective because they break decisions into manageable steps, minimize biases, address trade-offs, consider less quantifiable objectives, and incorporate subjective values.

MCDA is a methodical decision-making process that gained its popularity in the 1990's thanks to the rising economic thought that people make rational choices. Among over 200 MCDA techniques, classified according to their field and application (Zavadskas and Turskis, 2011; Cinelli *et al.*, 2020; Cinelli, Burgherr, *et al.*, 2022a; Taherdoost and Madanchian, 2023), various approaches have been employed to rank climate change mitigation policies and measures at both the local and national level. These methods have been applied in both developed (Konidari and Mavrakis, 2007; Streimikiene and Balezentis, 2013; Jayaraman *et al.*, 2015) and less developed countries (Xu *et al.*, 2011, 2017; Haque, 2016) to: a) urban energy systems, general urban planning (Faria *et al.*, 2018; Oppio, Bottero and Arcidiacono, 2018; Zavadskas *et al.*, 2018); b) ecosystem and land-use planning (Langemeyer *et al.*, 2016) and; c) individual public sustainable projects (Cavallaro, 2010; Wang, Yan and Xiao, 2012; Cai *et al.*, 2017; Juričić, Vašiček and Drezgić, 2020; Napoli *et al.*, 2020; Lombardi and Todella, 2023).

Additional to a multiple criteria analysis, a general systems approach (Bai *et al.*, 2016), project prioritization (Yang *et al.*, 2020), life cycle cost analysis (Stanford_University, 2005) and cost optimal methodologies (Hamdy, Hasan and Siren, 2013; Aelenei *et al.*, 2015; Brandão De Vasconcelos *et al.*, 2016) were applied to public sustainable projects for comparative analysis including multiple criteria. Regardless of the technique the principles have stayed the same, involving the general steps (Jankowski, 1995) outlined in Figure 1.

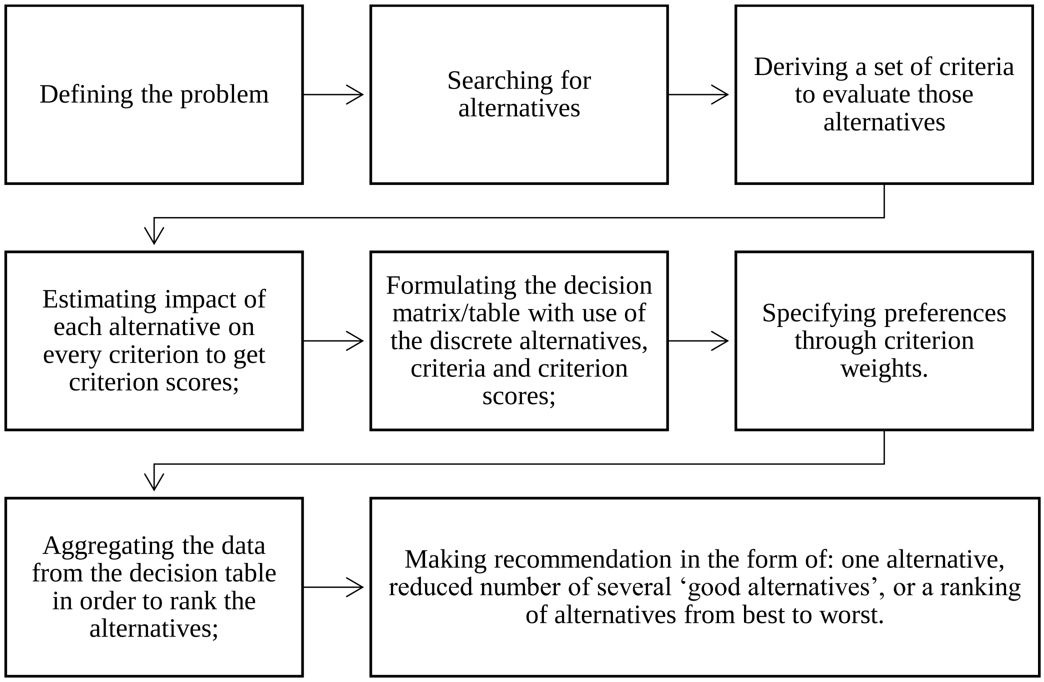



**Figure 3**: A general MCDA model adopted from Wątróbski et al., 2019.

*Source: Author*

MCDA models can be categorized based on various factors, such as complexity, data normalization, aggregation methods, treatment of uncertainty, compensation between criteria, trade-offs, and stakeholder preferences. A recent comprehensive review of over 200 MCDA methods categorizes them into three main approaches, grouped into 156 objectives (Cinelli *et al.*, 2020; Cinelli, Burgherr, *et al.*, 2022a). A simpler classification (Taherdoost and Madanchian, 2023) divides MCDA into:

- Function models vs. discrimination functions vs. outranking relations vs. utility functions
- Compensatory (trade-off-based) vs. non-compensatory (dominance relationships)
- Individual vs. group decision-making
- Qualitative vs. quantitative
- Certain vs. uncertain
- Multi objective decision making (MODM) vs. multi attribute decision making (MADM).

Going into further details of this categorisation, Zavadskas and Turskis (2011) present and overview of these two schools of thought which differ on what human choice is based on: the French discrete MADM (multi-attribute decision-making) methods and the American continuous MODM (multi-objective decision-making) methods.

The choice of MCDA method significantly impacts decision quality and outcome consistency, even when applying identical criteria weight to the same set of inputs (Németh *et al.*, 2019; Wątróbski *et al.*, 2019; Sałabun, Watróbski and Shekhovtsov, 2020; Więckowski and Zwiech, 2021). This consistency is vital for ensuring reliable and reproducible decision-making processes. Moreover, understanding how these methods handle the weighting and integration of criteria can provide insights into their suitability for specific decision-making scenarios.

MCDA methods broadly fall into compensatory and non-compensatory approaches. Compensatory models allow trade-offs between criteria, making them well-suited for prioritising sustainability actions and resulting in a ranking. In contrast, non-compensatory models impose strict minimum thresholds, ensuring that only alternatives meeting all essential criteria are considered, ultimately producing a map of acceptable alternatives rather than a ranked list (Greco, Ehrgott and José Rui, 2016). Since compensatory methods permit a low score in one criterion to be offset by a high score in another, they often employ weighting to reflect stakeholders' preferences regarding the relative importance of each criterion. Compensatory methods that allow for value judgement through assigning weights elicit most biases and may ultimately change the outcomes or the results of the decision-making process making it one of the biggest challenges in MCDA (Riabacke, Danielson and Ekenberg, 2012a).

Although Frini and Ben Amor (2019) argue that non-compensatory methods are more suitable for sustainable development decision problems—due to their ability to handle both qualitative and quantitative data without requiring normalization—compensatory or ranking methods remain widely used for their flexibility and applicability across diverse decision-making contexts.

Weight elicitation methods can be categorized into direct approaches (such as ranking, rating, and point allocation) and indirect methods (such as pairwise comparisons and best-worst scaling), depending on whether a single or multiple value judgments are required per criterion (van Til *et al.*, 2014). Mareschal (1988) highlighted the concept of stability intervals in weight sensitivity, meaning that within a certain range of weight variations, the final ranking of alternatives remains unchanged. This suggests that small fluctuations in stakeholder preferences may not necessarily impact overall prioritization. However, when weights approach thresholds where changes do affect rankings, decision-makers must be mindful of potential result instability. Furthermore, van Til et al. (2014) emphasize that this sensitivity in weight assignment is particularly pronounced in individual decision-making contexts, making direct comparisons across different techniques challenging. As a result, pairwise comparisons are often preferred for eliciting stakeholder preferences, as they facilitate a structured and consistent weighting process.

To mitigate the risks associated with weight sensitivity and model variability, several strategies can be employed: (a) reducing cognitive load by using indirect elicitation methods (e.g., pairwise comparisons) to minimize biases and simplify decision-making

(Riabacke, Danielson and Ekenberg, 2012b; Lolli *et al.*, 2019); (b) incorporating sensitivity analysis to identify the most influential criteria and ensure stability in the final ranking of alternatives (Riabacke, Danielson and Ekenberg, 2012b); and (c) selecting a well-suited MCDA method based on the specific decision-making context and stakeholder involvement, balancing accuracy, usability, and interpretability.

The often-cited problem of almost any MCDA technique is that weighted scoring ads further ambiguity and is easily affected by personal preferences and does not add to the credibility of the solutions (i.e. just because a policy maker weighs a certain criteria higher will not make it a more rational decision, but it will make the method rank it higher). Consequently, many turn to other methods for obtaining a clear unit of measure for which decision is better, such as the two methods covered in this section: (1) cost-benefit analysis (CBA); and (2) applied information economics (AIE).

### 2.2.2 Comparison with Cost-Benefit Analysis (CBA) and Applied Information Economics (AIE)

## Cost-Benefit Analysis (CBA)

CBA or the cost-benefit analysis is another important and well-known decision-making process. As opposed to MCDA where the purpose of the analysis is left to stakeholders to decide when shaping the criteria, the CBA has a set rationale – to improve allocation of (scarce) resources for an organisation, or in this case, a city or a region. Some economists (Nyborg, 2014) argue that CBA in context of public policy is far less objective than is often thought since, for social welfare projects it involves *highly controversial value* judgements.

Methods that have the largest impact on the bottom line are often preferred by decision-makers to easily justify their choices. However, they are inaccurate, in that they disregard many of the other benefits especially in energy efficiency where many additional benefits are not so obvious. Similarly, in adaptation actions, some risks are often not quantified due to the perception that risk is difficult to predict so the potential costs of damage remain hidden. Nyborg (2014) even goes further to argue that when used to measure welfare, it is based on highly controversial value judgments and when used to measure efficiency, it is based on assumptions of limited relevance to democratic decision-making processes. The second downside of the traditional CBA, besides this overfocus on economic efficiency which ignores environmental benefits, is that it is focused only on the quantifiable effects and has a single criterion, whereas there are multiple criteria to consider in deciding which sustainable actions to invest in first.  Finally, in practice, the impact of CBA and monetary valuation on actual policy-making appears to be limited

A comparative assessment of both approaches for sustainable measures, for the topic of mobility, was performed in 2012 (Beria, Maltese and Mariotti, 2012) which confirmed the above downsides of both the MCDA and CBA. The conclusion was that more quality decisions would be made by using both methods. However, having a more complicated approach lessens the probability that any systemic method will be applied at all. Usually, an MCDA would be performed when there is a long set of alternatives, or many measures to be implemented to narrow down the list. Then, a CBA can be performed for each of the remaining measures to result in comparable quantitative evaluation that can then be compared among the considered alternatives.

However, this process is still unfit for sustainable decision-making since CBA uses discounting – a method which basically reduces or ignores the future value of our current actions. Since most costly adaptation measures will have effect for decades to come (for example water dams which can successfully prevent flood damage for hundreds of years, and the longer the timeframe, the higher the probability that the certain environmental risk will occur).

## Applied Information Economics (AIE)

Another decision-making methodology, called applied information economics (AIE) overcomes both the challenge of MCDA being inaccurate in its ranges instead of assigning specific values, as well as the challenge of CBA including only "hard" or easily measurable criteria. It was developed by Douglas W. Hubbard aimed at helping organizations measure and manage risk and uncertainty and answer questions such as how to measure future uncertain risks or when to stop analysing, accept risk and make a decision. A book *How to measure anything* (Hubbard, 2014b) details that AIE combines several existing techniques, including statistical methods, economics, actuarial science, mathematics and information theory, to provide a more rigorous approach to decision-making. It does so by ensuring that harder to measure criteria is also considered for measurement if it is deemed valuable, by computing the value vs. cost of efforts of computing additional information. This enables reduction of uncertainty by identifying which so-called "soft" benefits to be measured with empirical methods and thus improving the quality and scope of information that enters the decision-making model. Some economic methods often used in AIE are (1) a Monte Carlo simulation to model the probability of different outcomes in a process with random variables, used to understand the impact of risk and uncertainty; (2) expected utility to mathematically model risk appetite of the organisation and calculate Certainty; (3) certainty monetary equivalent value to enable comparison of various investments; (4) loss exceedance curve for evaluating the overall risk for the organisation and to ensure proper risk management.

AIE also respects the importance of time as a variable in decision-making which affects both cost and value. For example, it considers the possibility of certain technology becoming more easily accessible and cheaper in the future, or that some feature will deteriorate in time. This enables long-term measures to gain importance as opposed to when using more traditional methods with usual discounting. Suppose that a city is considering building a new parking lot with solar roofs, but the solar part will not initiate for five more years due to land preparation, licences etc. Thus, after five years it can be expected that the price of PV has dropped. Often, such intricacies are not considered in decision-making, not because they are unnoticed – it can be reasonably assumed that most decision-makers consider this possibility – however, decision-makers may be uncertain about the magnitude of future price reductions. Thus, unable to tackle this uncertainty, such price-dropping factor might be considered overly speculative and would be avoided all together, making perhaps an excellent investment deem much less feasible.

AIE framework typically includes the following steps, aiming to provide a structured and rigorous approach to decision-making, helping organizations manage risk, reduce uncertainty, and make more informed decisions:

1. Define the Decision: Clearly define the decision that needs to be made, including the objectives and the criteria that will be used to evaluate the decision.
2. Determine What You Know: Collect and summarize all the relevant data and information that is already available. This can include both quantitative data and qualitative information.
3. Compute the Value of Additional Information: Use the data and information gathered to calculate the value of obtaining additional information. This involves assessing the impact that additional information could have on reducing uncertainty and improving the decision-making process.
4. Conduct a Measurement: Based on the calculation of the value of additional information, decide whether to proceed with obtaining additional data. If it is determined that additional data is worth obtaining, conduct the necessary measurements or gather the required information.
5. Update Beliefs: Use the new data to update your beliefs or assumptions about the decision. This could involve updating statistical models, adjusting probability distributions, or revising estimates.
6. Make a Decision: With the updated information, make the final decision. Ensure that the decision is consistent with the objectives and criteria defined in the first step.
7. Track the Results: After the decision has been made, track the results and outcomes to assess the accuracy of the decision and the effectiveness of the AIE process. Use this information to refine and improve future decision-making processes.
8. Document and Communicate the Results: Finally, document the decision-making process, including the data and information used, the analyses conducted, and the rationale for the decision. Communicate the results to all relevant stakeholders.

The limitations of the AIE approach include its time-intensive nature and its reliance on the subjective judgments of so-called “calibrated” experts—individuals trained to assess risks with informed accuracy. As such, the robustness of the process is inherently linked to the preparedness and decision-making competence of the participants. Nonetheless, the inclusion of relevant stakeholders in the decision-making process tends to enhance the overall quality of outcomes. Effective collaboration is widely recognised as a key predictor of the successful implementation of measures. Therefore, when the issue is deemed significant enough to warrant the AIE approach, its application can help reduce uncertainties and improve the quality of decisions.

Even when the AIE framework is not applied in full—particularly when economic evaluation methods are excluded—it still provides a valuable conceptual foundation. These principles can be integrated into simpler, existing decision-making processes to foster greater consistency and rigour.

### 2.2.3 Uncertainty and Cognitive Bias in Decision-Making

A problematic and often criticized stage in multiple criteria decision-making is turning information on each of the criteria into comparable numerical data such as impact grades and scores, and assigning weights, since this is where subjective human judgment surfaces.

It has been over half a century since psychologist Paul Meehl performed his experiment comparing actuarial with clinical methods in decision-making, or, more simply, comparing statistical algorithms with subjective judgment, and concluded that algorithms almost always outperformed human judgement (Grove and Meehl, 1996b). This implies that even an imperfect algorithm can outperform human judgment, decision-makers are often reluctant to make extra effort to make extra quantifications and some modelling to understand the benefits and costs of their alternatives, as well as the risks involved and reducing uncertainty about future events. The literature shows there are often two reasons why decision-makers do not undertake such measurements: (1) Measurement aversion is evident, a principle where organisations measure what is easy to measure rather than measuring values which would provide greater benefits or avoid higher costs and (2) the uniqueness fallacy is present where they believe that their situation is unique and fail to realise that one can always learn from examining other situations, no matter how unique a certain situation seems (Hubbard, 2014b). Additionally, there is research on whether people actually make rational choices with some evidence that, even when some decision-making algorithms are employed, decision-makers do not follow the normative theories in reality (Hahn and Tetlock, 2008b). They further find that, although the rising interest in the use of economic tools such as CBA is evident, the commonly accepted guidelines are not met, thus making faulty models.

When they do employ decision-making method however, it is important to monitor outcomes to check whether those methods actually work and to entice learning from the process. Daniel Kaheman, the only psychologist to receive a Nobel prize in Economics for his exploration of cognitive biases, explored how human mind can make error judgements with our automatic thought processes. This occurs because, if the method is flawed, but structured and formal, decision-makers' perception about the result is better, although there is no proof the method works (Hubbard, 2014b). Hubbard calls this the *analysis placebo*, or *the general pluralistic ignorance*. In simple terms, people are more reluctant to question or challenge the results if the method is complex.

**Table 4:** A summary of descriptive models of decision-making and their applications to decision-making for sustainability.

| Model and related concepts | Definition | Examples of applications to decision-making for sustainability |
|---|---|---|
| PROSPECT THEORY | The view that decision-makers tend to (1) over-weight outcomes that are certain (relative to outcomes that are probable), (2) place a higher absolute value on losses relative to equivalent gains and (3) judge losses and gains relative to an easily accessible reference point (e.g. their current situation). | This theory informs communication efforts relating to sustainability issues (e.g. climate change). Messages that are framed in terms of avoiding future losses appear to be more effective than those highlighting future gains. |
| Endowment Effect | Property in our possession and our current state of being are automatically endowed with greater value. | In the face of difficult sustainability-related decisions, people often stick with the status quo to avoid confronting difficult trade-offs or dealing with complex information (highlighting the need to employ structured decision-making techniques). The tendency to stick with the status quo can also be exploited in certain circumstances to ensure more sustainable choices are made, e.g. offering sustainable options as a default choice will increase the likelihood they will be selected. |
| Loss Aversion | An aversion to losing property in our possession (even if only randomly or recently acquired) or to losses relative to our current state of being. | |
| Status Quo Bias | The reluctance to adopt new behaviours or give up property already in our possession (because of the endowment effect and aversion to loss) | |
| HEURISTICS AND BIASES | Heuristics are decision short-cuts or “rules of thumb” employ in everyday lives. | Decision heuristics are helpful much of the time, but can result in systematic and predictable errors and biases in our decision-making (particularly in complex and unfamiliar decision-making contexts). |

| | | |
|---|---|---|
| Availability Bias | The tendency for decision-makers to gauge the likelihood that an event will occur because of the ease with which similar events can be brought to mind (regardless of the number of times the event has actually occurred). This bias is also true for events that are particularly vivid and/or associated with strong emotions. | Decision-makers may feel insufficiently motivated to act if salient or vivid examples of sustainability-related issues (e.g. climate change or air quality) cannot be easily brought to mind. In other circumstances, decision-makers may over-weight issues for which they have recent or particularly vivid examples (e.g. the perceived risks associated with nuclear power may be now be heightened because of the accident at the Fukushima Daiichi nuclear plant). |
| Anchoring With Insufficient Adjustment | The tendency for decision-makers to base (or "anchor") their judgment on some initial — and often unrelated — reference point. | Judgments about the costs associated with environmental degradation (e.g. in dollars, lives lost, species extinctions) can be influenced by numeric values suggested or picked up on during the decision-making process — even if those suggested values are fictional or are not relevant to the decision at hand. For example, estimates of the severity of climate change were influenced by initial suggestions regarding how much the earth's temperature was expected to increase. |
| Evaluability | In the absence of suitable points of comparison, decision-makers will often focus on easy-to-evaluate characteristics and ignore more difficult-to-evaluate characteristics (even if they are more important for the decision at hand). | When deciding on a particular decision option, cost (an easy-to-evaluate characteristic) may trump more difficult-to-evaluate characteristics such as scenic beauty, quality of life or species extinctions. |

| | | |
|---|---|---|
| AFFECT AND DUAL PROCESSING PERSPECTIVES | Our understanding of the world comes from the simultaneous operation of two systems: (1) the Experiential System, which is intuitive and automatic and (2) the Analytic System, which is deliberative and effortful. The main characteristic of our experiential system, affect, is defined as an emotional feeling- state that people express in terms of happiness or sadness, goodness or badness. These assessments occur rapidly and automatically, without conscious effort. | Affect is often employed to help explain why we overreact to some issues (e.g. terrorism and accidents at nuclear power plants, which can elicit a strong affective reaction, despite the probabilities of occurrence being low) and underreact to others (e.g. climate change and genocide, which may elicit an insufficient affective reaction despite pressing societal problems). The tendency to over-rely on affect and the affect heuristic (at the expense of the analytic/deliberative system) is exacerbated when the decision-maker faces difficult or unfamiliar choices, or when he or she is tired, distracted or hungry. |
| Affect Heuristic | The tendency for decision-makers to rely on affective feelings during judgment and decision-making; in other words, use of an affect heuristic leads to judgments about objects, activities and other stimuli that are quick, intuitive and without conscious effort. Affect and the affect heuristic have been invoked to help explain availability bias, evaluability bias, and the want/should and present/future conflicts described below. | |
| WANT/SHOULD AND PRESENT/ FUTURE CONFLICTS | One often faces decisions in which one must choose between satiating an immediate "want" vs. holding out for a later "should". "Wants" are typically choices that provide immediate satisfaction or pleasure, but have negative longer-term consequences. "Shoulds" are choices that may not be immediately pleasurable, but that provide benefits over the longer term. The conflict between "wants" and "shoulds" is | The tendency to satisfy "wants" (e.g. driving a car, buying a cheaper but less efficient furnace or putting short-term profit ahead of environmental remediation efforts) at the expense of "shoulds" (e.g. taking public transit, buying a high-efficiency furnace or investing in remediation technology) can interfere with the achievement of sustainability goals. |

| | | |
|---|---|---|
| | exacerbated by our tendency to consider and weigh the future differently from the present. In most decision-making circumstances, the present is given much more weight than the future (a phenomenon known as discounting). | |
| CONSTRUCTION OF PREFERENCE | Collectively, descriptive models of decision-making illustrate that decision-makers often construct their preference for a particular option or course of action “on the spot” in response to cues that are available during the decision-making process (e.g. through the use of heuristics or affective reaction). | The construction of preference is most likely to occur when people face decisions that are unfamiliar, require trade-offs among closely held objectives and where outcomes are difficult to quantify (e.g. the choice between scenic beauty or saving endangered species conflicts with issues of costs, jobs or profit, which often characterize decision-making for sustainability). Decision-support techniques should approach decision-making as a process of carefully constructing participants’ preferences (based on their fundamental values relevant to that particular decision). Other kinds of decision-support efforts serve to subtly change the context within which decisions are made, such that sustainable choices are more likely to be made. |

*Source: Network for Business Sustainability, 2012, p. 21-22 (Network for Business Sustainability, 2012b).*

## 2.3 From Theory to Application: MCDA Tool Development

### 2.3.1 Selecting an Appropriate MCDA Method

Applying the appropriate MCDA technique is a crucial step in performing MCDA and there have been multiple attempts to present a comprehensive framework for MCDA method selection (Wątróbski *et al.*, 2019; Cinelli, Burgherr, *et al.*, 2022b). Watróbski et al. (2019) developed a free web-based tool for choosing a proper MCDA method (MCDA, 2019) out of 56 available MCDA methods and they also comment on differences between what literature suggests and what experts use in practice. Cinelli et al. (2022b) studied the use of MCDA methods in energy systems analysis and found that approximately 60 percent of researched case studies used a suboptimal model for the type of problem presented. Their model incorporates 156 features of 105 methods and six overall guidelines, among which is that *the interdependencies between the criteria can refine the preference model* and subsequently a free web-based tool was developed for choosing a proper MCDA method (MCDA-MSS, 2023).

**Table 5:** Questions for taxonomy of MCDA methods.

| Section | Question context | Questions used to describe the method | Questions used to describe the case study |
|---|---|---|---|
| 1: Problem typology | Problem statement | What type of decision recommendation does the method provide? | What type of decision recommendation is requested? |
| | Order of alternatives if ranking as a problem statement was chosen | Does the method provide a partial or complete order of alternatives as a final decision recommendation? | Is complete order of alternatives as a final decision recommendation required , or would a partial one be enough? |
| | Structure of the set of criteria | Can the method accept a flat and/or hierarchical structure of the criteria? | Is the structure of the criteria flat or hierarchical? |
| 2: Preference model | Comparison of the performances on all the criteria | How does the method perform the comparison of the performances on the criteria? | How should the comparison of the performances on the criteria be performed? |
| | Compensation between criteria | What is the level of compensation between the criteria performances | How much can the good performance on a criterion compensate for |

| Section | Question context | Questions used to describe the method | Questions used to describe the case study |
|---|---|---|---|
| | | that the method implements? | the bad performance on another criterion? |
| 3: Elicitation of preferences | Type of weights, if the user wants to use criteria weights | Does the method accept precise and/or imprecise weights? | Should precise or imprecise weights be used in this case study? |
| | Type of pairwise comparison thresholds if the user wants to use pairwise comparison thresholds | Which type, if any, of pairwise comparison thresholds does the method accept? | What type of pairwise comparison thresholds should be used? |
| | Interactions between criteria | What type, if any, of interactions can the method handle? | What type, if any, of interactions should be handled? |
| 4: Exploitation of the preference relation induced by the preference model | Type of exploitation of the preference relation induced by the preference model | Which type of exploitation of the preference relation induced by the preference model does the method support? | What type of exploitation of the preference relation induced by the preference model should be applied for this case study? |
| | Type of output variability analysis, if the user indicated that output variability analysis be performed | What type, if any, of output variability analysis can the method perform? | How should the output variability analysis be conducted? |

*Source: Cinelli, Kadziński, et al., 2022*

### 2.3.2 Systematic Review of Urban MCDA Applications

Multi-Criteria Decision Analysis (MCDA) methods have been increasingly applied in urban sustainability contexts, particularly in energy and climate action planning. Among these, the Analytic Hierarchy Process (AHP) remains the most prevalent method, noted for its versatility and applicability to sustainable development (Zyoud and Fuchs-Hanusch, 2017; Bruen, 2021a; Stofkova *et al.*, 2022)

According to Mardani et al. (2016b), the most frequently used MCDA techniques include:

1. AHP and Fuzzy AHP (F-AHP),
2. Analytic Network Process (ANP) and VIKOR,
3. TOPSIS and Fuzzy TOPSIS (F-TOPSIS),
4. PROMETHEE,
5. Integrated and hybrid methods,
6. Other specialised approaches.

The conclusion was that there is a rising interest for these techniques to *assist stakeholders and decision-makers in unravelling some of the uncertainties inherent in environmental decision-making* in projects regarding sustainable and renewable energy systems.

Cajot *et al.* (2017a) reviewed 89 urban energy planning studies across 58 journals, reinforcing the dominance of AHP/ANP, WSM (Weighted Sum Method), MODM (Multiple Objective Decision Making), TOPSIS, and ELECTRE, each appearing in at least five separate studies.

Additional methods cited in urban sustainability research include:

- MACBETH (Faria *et al.*, 2018),
- SAW/WSM (Cavallaro, 2010; Milakis and Athanasopoulos, 2014; Frieyadie, Sukmawati and Nurajijah, 2020; Kurniawati, Lenti and Nugroho, 2021),
- ELECTRE III (Cavallaro, 2010; Govindan and Jepsen, 2016),
- MULTIMOORA – multiobjective optimization by ratio analysis plus full multiplicative form method (Stanujkic *et al.*, 2015).

These techniques have been used not only in local urban contexts but also at national levels for prioritising climate change mitigation measures in both developed and developing countries (Konidari and Mavrakis, 2007; Xu *et al.*, 2011, 2017; Streimikiene and Balezentis, 2013; Haque, 2016).

Urban-specific applications of MCDA have further highlighted hybrid approaches that enhance decision relevance. These include:

- AHP variants such as level-specific pairwise comparison (Giaccone *et al.*, 2017),
- AHP integrated with GIS (Bojórquez-Tapia *et al.*, 2011; D'Orso *et al.*, 2023),
- NSGA-II combined with AHP for national energy planning (Haydt, Leal and Dias, 2014a),

- MODM in smart city energy optimisation (Carli, Dotoli and Pellegrino, 2015, 2018).

Mirakyan and De Guio (2013) and Moussavi Nadoushani et al. (2017) also emphasise the value of MCDA in facilitating structured, transparent prioritisation of sustainability actions, particularly when multiple stakeholders and trade-offs are involved.

Several families of MCDA methods are observed across the literature, each offering different strengths and trade-offs. While AHP is the most widely applied due to its simplicity, limitations such as the assumption of independent criteria and potential judgment inconsistencies have led to the adoption of more advanced methods (Velasquez and Hester, 2013; Giaccone *et al.*, 2017). ANP, PROMETHEE, ELECTRE, and fuzzy extensions are frequently adopted to overcome these issues.

Outranking methods such as ELECTRE and PROMETHEE are often used in contexts involving qualitative or conflicting criteria, particularly where full compensability is not appropriate. These have been applied to energy retrofit evaluations, marginalised communities, and broader public policy decisions (Lopez, Noriega and Chavira, 2017; Napoli *et al.*, 2020). In contrast, value-based methods like MAUT and MAVT offer highly structured modelling of stakeholder preferences but require extensive data and technical sophistication.

Hybrid approaches are increasingly favoured, particularly those integrating MCDA with GIS (D'Orso *et al.*, 2023), fuzzy logic, or optimisation algorithms. Fuzzy MCDA models have gained popularity for handling subjective or uncertain data (Mardani *et al.*, 2016) although questions about model transparency and sensitivity to fuzzy parameters remain (Yatsalo, Radaev and Martínez, 2022).

Critically, in their analysis of current MCDA for sustainability, Frini and Ben Amor (2019) challenge the suitability of scoring-based MCDA techniques for sustainable development. They argue that compensatory logic is inappropriate for sustainability trade-offs, and advocate for outranking methods, which incorporate thresholds and support heterogeneous data without normalisation.

In sum, AHP and its hybrids are most frequently applied, valued for their simplicity and adaptability. It is pivotal to understand that the choice of a decision-making method is heavily influenced by the intricacies of the problem at hand, the data available, and the inclinations of the decision-makers. Other methods, such as PROMETHEE and ELECTRE, are employed for more complex or uncertain decision environments. Each technique brings a unique perspective to evaluating alternatives against diverse sustainability criteria. A clear trend is the move toward hybrid and flexible methods that improve robustness and usability in real-world sustainability planning. A comparative overview of these methods, including benefits and limitations, is presented in **Table 6**.

There is an existing body of literature for selecting the appropriate MCDA techniques in various sustainable fields, such as for adaptation actions under different conditions

(Institute for Global Environmental Strategies, 2014), technical evaluations in energy efficiency (Juričić, Vašiček and Drezgić, 2020) waste management (Lombardi and Todella, 2023), civil engineering construction and building technology (Zavadskas *et al.*, 2018), among others. However, no research yet covers both adaptation and mitigation measures as part of a single decision-making process.

In conclusion, method selection in urban MCDA depends on the complexity of the problem, available data, stakeholder needs, and treatment of uncertainty.

**Table 6:** Characteristics and Applications of Common MCDA Techniques in Climate and Urban Planning.

| Method | Description / Key Feature | Application in Sustainability Context | Source |
|---|---|---|---|
| AHP | Uses pairwise comparisons to derive weights from expert judgments. | Widely used for prioritising sustainability criteria and actions. | (Mirakyan and De Guio, 2013; Moussavi Nadoushani *et al.*, 2017; Sébastien Cajot *et al.*, 2017b; Carli, Dotoli and Pellegrino, 2018; Stofkova *et al.*, 2022) |
| Fuzzy AHP | Integrates fuzzy logic to handle uncertainty and vagueness in expert input. | Useful when data or preferences are imprecise or subjective. | (Kutty *et al.*, 2023) |
| AHP + GIS | Combines spatial analysis with structured criteria weighting. | Site suitability for renewable energy, green infrastructure planning. | (D'Orso *et al.*, 2023) |
| NSGA-II + AHP | Multi-objective evolutionary algorithm combined with AHP for preference structuring. | Optimizes trade-offs between sustainability goals (e.g., cost vs emissions). | (Haydt, Leal and Dias, 2014b) |
| SAW (with AHP) | Simple additive weighting method, often used in combination with AHP for ranking. | Urban project ranking and infrastructure prioritisation. | (Cloquell-Ballester *et al.*, 2007; Kurniawati, Lenti and Nugroho, 2021) |
| ANP | Generalization of AHP allowing interdependencies between criteria. | Applied to complex planning problems like transportation or energy. | (Xu *et al.*, 2011) |

| **Method** | **Description / Key Feature** | **Application in Sustainability Context** | **Source** |
|---|---|---|---|
| TOPSIS | Ranks alternatives based on distance to ideal solution. | Used for evaluating urban sustainability or policy options. | (Cai *et al.*, 2017) |
| ELECTRE | | | (Haydt, Leal and Dias, 2014a; Govindan and Jepsen, 2016) |
| ELECTRE III | Outranking method accommodating uncertainty and partial preferences. | Suitable for environmental and energy decision-making. | (Cavallaro, 2010; Milakis and Athanasopoulos, 2014) |
| MULTIMOORA | Ratio-based MODM technique; incorporates normalization and multiplicative forms. | Employed in city-level energy planning. | (Streimikiene and Balezentis, 2013) |
| MACBETH | Qualitative technique based on value judgments, often combined with cognitive mapping. | Applied to assess urban quality of life. | (Bana e Costa, De Corte and Vansnick, 2011; Faria *et al.*, 2018) |
| VIKOR | Focuses on ranking and selecting from alternatives based on closeness to the ideal solution with compromise. | Applied in sustainable energy and policy decision-making. | (Mardani *et al.*, 2016) |
| PROMETHEE | Outranking method that evaluates alternatives based on preference functions and partial rankings. | Applied in energy and environmental project assessments. | (Govindan and Jepsen, 2016) |

*Source: Author*

### 2.3.3 Survey of Existing MCDA Tools

Once the proper model was identified, it can be applied either with or without the software, depending on its complexity. The application of most decision-making models, other than non-weighted models, or ones with weighted sum or weighted products, requires either an extensive knowledge of Excel or statistical languages such as R programming, or a specialized software for more complex decision problems.

However, selecting the appropriate MCDA method is a critical issue in itself, and 60% of case studies of MCDA applied to energy systems employed suboptimal models for their problems (Cinelli, Burgherr, et al., 2022). Several frameworks have been developed to aid in this process (Cinelli et al., 2021; Cinelli, Kadziński, et al., 2022a), including a free web-based tool that helps users choose from 56 available MCDA methods and highlights discrepancies between literature recommendations and expert practices (Wątróbski et al., 2019).

Dragovic Matosovic (2024) gives a list of up-to-date, free MCDA tools applicable to sustainability (**Table 7:** Up-to-date MCDA tools). However, cataloguing the available MCDA software packages, Bruen (2021b) concludes that, although many of these tools are available at no cost, they remain rarely cited in literature and are thus underused in both engineering and sustainability.

**Table 7:** Up-to-date MCDA tools.

| **Tool Name** | **Description** |
|---|---|
| CimactPrio (IHS, n.d.) | An MCDA tool for cities to identify and prioritise their adaptation and mitigation actions. It offers a framework on how to define a strategy, choose actions and engage stakeholders' opinions. It consists of two separate tools; one for mitigation and one for adaptation actions and uses weights and normalization to prioritize actions |
| Decision-deck (Decision Deck, 2021a) | Another example of a hub for different Open Source software tools for implementing Multi-Criteria Decision Aiding techniques, including *the GIS Initiative* (Decision Deck, 2021b) which aids the integration of Geographical Information Systems and Multi-Criteria Decision Aiding, as well as *diviz*, a workbench to design, execute and share complex MCDA algorithms and experiments which currently integrates ACUTA, ELECTRE, ELECTRE TRI and PROMETHEE methods. |
| DEXi (DEXi, 2025) | Developed in Slovenia for a simplified qualitative multi-attribute modelling, DEXi employs value sets instead of value distributions and models developed by DEXi are |

| | |
|---|---|
| | suitable for solving sorting/classification decision-analysis tasks, where options need to placed in a finite number of predefined categories. |
| Das Entscheidungsnavi (ENTSCHEIDUNGSNAVI, 2025) | An online simple to use free MAUT tool which incorporates value-focused thinking and is the most appropriate for individual decision-making. |
| PAPRIKA (1000minds, 2025) | A 1000minds software, freely available for academic use which uses AI to help easily generate adaptable models. It is available for a free two-week trial or free for researchers in some cases. |
| RightChoice (Ventanta Systems UK, n.d.) | An ANP MCDA tool free for researchers |
| Super Decisions (Creative Decisions Foundation, 2025) | A software implementing AHP and ANP methods and allows for a sensitivity analysis, enabling inclusion of intangibles in decision making. It offers many free preset models across areas, including local policy making. |

*Source: Author*

The prior mentioned key challenge of effective utilization of synergies in urban areas can be solved through using tools for decision-making. Despite the literature strongly supporting the idea that both developed and developing countries need innovative, cross-sectoral, multi-criteria tools and methodology for both local synergistic planning (Landauer, Juhola and Söderholm, 2015), as well as national reporting on sustainable actions (Martín-Ortega *et al.*, 2024), existing tools do not integrate different planning segments (Mirakyan & De Guio, 2013b), and adaptation and mitigation aspects are often separately valued.

Latter meta-research is perhaps the most inclusive decision-making research mapping useful methods and tools used for integrative energy planning. It builds on earlier meta-research (Wang *et al.*, 2009) reviewing MCDA methods in the different stages of sustainable energy planning and decision-making (i.e., criteria selection, criteria weighting, evaluation and final aggregation) and (Zhou, Ang and Poh, 2006) covered more than 270 references to classify the MCDA methods according to the problem types that may be analyzed using the appropriate methods. The predominant factors influencing policymakers' selection of specific MCDA methods in the context of urban energy systems are their popularity or widespread usage, their intuitive or straightforward nature, and their capacity to integrate both qualitative and quantitative data (Cajot, Mirakyan, et al., 2017).

Most existing tools focus on prioritizing adaptation (Institute for Global Environmental Strategies, 2014; Covenant of Mayors for Climate & Energy EUROPE, 2016), or mitigation actions (Drozdz, 2011; De Miglio, Chiodi and Burioli, 2016; Mosannenzadeh, Di Nucci and Vettorato, 2017), or both separately (IHS Erasmus University Rotterdam, UN-HABITAT and ICLEI World Secretariat, 2014), but comprehensive guidance that integrates both adaptation and mitigation measures remains insufficient.

### 2.3.4 Comparative Review of Sustainability Frameworks

The problem of including synergies can be overcome with using the right criteria to make sure that both the mitigation and adaptation objectives are achieved, all under a prior mentioned TBL lens of economic, social and environmental wellbeing. Under these overarching objectives, there are many criteria to choose from, and following is an overview of indices and criteria for evaluating SECAP measures.

There have been many attempts to benchmark urban planning and standardize sustainable indicators by European Union and its agencies (Dale and Beyeler, 2001; Directorate-General for Environment (European Commission) *et al.*, 2015; European Union, 2015; Mäkinen *et al.*, 2018; Science for Environment Policy, 2018), or by other authors focusing on: (1) urban development for smart and sustainable cities (Mori and Christodoulou, 2012; Joss and Rydin, 2018; Lehner *et al.*, 2018; Shmelev and Shmeleva, 2019); (2) country-level indicators (Stankevičienė, Sviderskė and Miečinskienė, 2014; Buggin *et al.*, 2019); or (3) corporate-level indicators (Rahdari and Anvary Rostamy, 2015) applicable to local level. Meta reviews of urban sustainability assessments (Mori and Christodoulou, 2012; Cohen, 2017; Dizdaroglu, 2017; Michalina *et al.*, 2021) attempted to systemize existing frameworks, while multiple European funded projects published guidance on harmonising Sustainable energy action plans (SEAPs) and Sustainable urban mobility plans (SUMPs) (Tomasi, 2018), or better understanding the impact of local adaptation actions (Biseniece, Rošā and Jēkabsone, 2023). Michalina et al. (2021) reviewed 50 urban sustainability indicator frameworks (USIFs) and listed the 38 most used indicators for clearly measuring and assessing sustainable criteria. Table 1 provides an original overview of 33 city and national sustainable frameworks considered in creating SYNERGISE+, which were available in English and had a cross-sectoral focus.

**Table 8:** Overview of existing sustainable indices.

| Sustainable framework | Year | Short description | Author/ Reference |
|---|---|---|---|
| **1. The 13 leading urban sustainability frameworks were identified for their robust methodologies, policy relevance, and decision-making applicability:** | | | |
| CDP ICLEI Track – Common Reporting Framework | 2018 | A partnership between CDP and ICLEI providing a platform for cities to disclose environmental data and track climate action progress. Since 2024, the Cities questionnaire is aligned with the reporting requirements of several initiatives including the GHG protocol and UNFCC's campaigns. | www.cdp.net/en (CDP and ICLEI, 2023) |
| d | 2016 | The EBRD Green City Action Plan (GCAP) is a structured strategic framework with 114 indicators assessing urban environmental challenges across 20 categories covering key sectors including energy, transport, water, waste, and land use. Grounded in the Pressure-State-Response (PSR) model, the GCAP quantitatively evaluates environmental issues by analysing the pressures on the environment, the current state of environmental conditions, and the policy or investment responses enacted to mitigate these pressures. While the methodology is primarily environmentally focused, it allows for the qualitative identification of actions that contribute positively to social objectives and economic growth. | https://www.ebrdgreencities.com/assets/Uploads/PDF/Green-City-Action-Plan-Methodology.pdf (EBRD, 2016) |
| ECPI – energy and climate policy Interactions | 2006 | A decision support tool for qualitative ex-ante assessment of interactions of energy and climate policy instruments in cities across | (Oikonomou and Jepma, 2008) |

| Sustainable framework | Year | Short description | Author/ Reference |
|---|---|---|---|
| | | four objectives: climate change mitigation, energy effectiveness, socioeconomic competitiveness, and technology. | |
| EUGCI – EU Green City Index | 2009 | A ranking system started by siemens, which assesses environmental performance in European cities, including energy, water, air quality, and waste management. | (Economist Intelligence Unit, 2009) |
| InSMART – Integrated Smart City Planning | 2017 | A EU-funded methodology combining quantitative modelling with qualitative stakeholder engagement to support decarbonization in EU cities and optimize smart city development, integrating energy, transport, and land-use planning. | http://www.insmartenergy.com (Gargiulo *et al.*, 2017) |
| Life SEC ADAPT – LIFE Programme project for climate adaptation in municipalities | 2019 | A project under the LIFE Programme aimed at strengthening climate adaptation planning in local municipalities across Europe. | www.lifesecadapt.eu (Life SEC Adapt Project, 2019) |
| PROSPECT City Capability Assessment Framework | 2020 | An integrated framework from Horizon 2020 project PROSPECT measuring city's general success factors in implementing sustainable actions, focusing on city planning, financing, and implementation capacity. | https://h2020prospect.eu/ (Spyridaki *et al.*, 2020) |
| RFSC – Reference Framework for Sustainable Cities | 2016 | A European framework for urban sustainability planning and governance which provides guidance for cities to develop integrated and sustainable urban strategies aligned with EU policies. | http://www.rfsc.eu/ (Cerema, 2016) |

| Sustainable framework | Year | Short description | Author/ Reference |
|---|---|---|---|
| SDG EU Cities Index | 2018 | A prototype index measuring the progress of European cities towards achieving 15 of the 17 UN SDGs. | euro-cities.sdgindex.org/ (Lafortune *et al.*, 2019) |
| SDEWES – Sustainable Development of Energy, Water, and Environment Systems Index | 2002 | A framework for evaluating urban sustainability, focusing on energy, water, and environmental systems. | https://www.sdewes.org/ (Kilkiş, 2015) |
| Smart and Sustainable City Assessment Methodology | 2015 | Multidimensional sustainability benchmarking for smart megacities with 20 criteria across 8 dimensions, based on sustainability and technological innovation. | (Shmelev and Shmeleva, 2019) |
| Smart Florence Plan | 2014 | A smart and sustainable city strategy for smart and sustainable urban development in Florence, Italy. | (Comune di Firenze, 2015) |
| SSI – Sustainable Society Index | 2006 | A framework measuring sustainability performance in cities and countries based on social, environmental, and economic well-being indicators. | www.ssfindex.com/ (Van de Kerk and Manuel, 2008) |
| **2. Other sustainability frameworks considered (not included in the comparative analysis):** | | | |
| **2.a City-Level and Regional Sustainability:** | | | |
| ARCADIS Sustainable Cities Index | 2016 | Evaluates 100 of the world's leading cities based on 52 sustainability metrics across planet, people, and profit. | www.arcadis.com/en/solutions/sustainable-cities/sustainable-cities-index Reviewed by (Shmelev and Shmeleva, 2019) |

| Sustainable framework | Year | Short description | Author/ Reference |
|---|---|---|---|
| Cities in Motion Index by IESE | 2014 | A ranking system and an urban model that evaluates cities based on four main drivers: sustainable ecosystems, innovative activities, equitability among citiziens and connected territory. | https://citiesinmotion.iese.edu/indicecim/ |
| Corporate Knights Sustainable Cities Index | 2022 | Ranks global cities on sustainability measures such as air quality, emissions, renewable energy, and waste management. | https://www.corporateknights.com/sustainable-cities/ |
| Economist Intelligence Unit's Global Liveability Index | 2002 | EIU's index ranks 173 cities across five categories: stability, healthcare, education, culture and the environment, and infrastructure. | https://www.eiu.com/n/campaigns/global-liveability-index-2024<br>Reviewed by (Shmelev and Shmeleva, 2019) |
| EU Regional Competitiveness Index | 2010 | Measures the major factors of competitiveness for all NUTS-2 level regions across the EU. | https://ec.europa.eu/regional_policy/en/information/maps/regional-competitiveness/ |
| Smart Cities Ranking of European medium-sized cities by the Vienna University of Technology | 2007 | Ranks specifically European medium-sized cities based on smart city factors over 6 areas: Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment, Smart Living governance, environment, and mobility. | (Vienna University of Technology, 2007) |
| GGGI - Green Growth Index by Global Green Growth Institute | 2019 | Measures country's performance in SDGs, Paris Climate Agreement, and Aichi Biodiversity Targets through four dimensions: efficienct and sustainable resource use, natural capital protection, green economic opportunities, and social inclusion. | https://gggi.org/<br>(Acosta *et al.*, 2020) |

| Sustainable framework | Year | Short description | Author/ Reference |
| --- | --- | --- | --- |
| Global Destination Sustainability Index (GDS-Index) | 2016 | The Index uses 77 indicators that evaluate destinations' sustainability performances across four key areas, including destination management, suppliers, and social and environmental factors. | https://www.gds.earth/ |
| ISO/TC 268 SC1 Smart Communities Infrastructure | 2012 | Focuses on technical aspects of smart community infrastructure which are basic structures that support the operation and activities of urban communities, e.g. energy, water, resource management systems, ICT infrastructure. | https://www.iso.org/committee/656967.html |
| ISO 37101 Sustainable developent in communities standard | 2014 | The first international standard on city indicators, revised in 2022. | www.iso.org/standard/68498.html (McCarney, 2015) |
| Mori Foundation's Global Power City Index (GPCI) | 2017 | A very broad index focusing on 70 indicators applied to 44 cities. It evaluates and ranks the major cities of the world according to their comprehensive power to attract people, capital, and enterprises from around the world, through measuring 6 functions—Economy, Research and Development, Cultural Interaction, Livability, Environment, and Accessibility. | https://mori-m-foundation.or.jp/english/ius2/gpci2/index.shtml Reviewed by (Shmelev and Shmeleva, 2019) |
| IMD Smart Cities Index by World Competitiveness Center | 2024 | Assessing the two pillars of cities for which perceptions from residents are solicited on five key areas: health and safety, mobility, activities, opportunities, and governance. The two pillars are: the Structures pillar referring to the existing infrastructure of the cities, and the Technology pillar describing the technological provisions and services available to the inhabitants. | https://www.imd.org/smart-city-observatory/home/methodology/ |

| Sustainable framework | Year | Short description | Author/ Reference |
|---|---|---|---|
| Rockefeller Foundation's Resilient Cities Index | 2014 | Designed to enable cities to measure and monitor the multiple factors that contribute to their resilience, structured around four dimensions, 12 goals and 52 indicators. | (the Rockefeller Foundation and Arup, 2014) Reviewed by (Shmelev and Shmeleva, 2019) |
| The Cities of the Future Index by EasyPark | 2017 | Reveals and ranks the most intelligent cities in the world across four areas, with 14 topics and 50 indicators on how intelligent and sustainable a city is. The four areas covered are: digital life of a city's inhabitants, mobility innovation, business tech infrastructure, and environmental footprint. | https://easyparkgroup.com/studies/cities-of-the-future/en/ |
| STAR (Sustainability Tools for Assessment and Rating) Community Index | 2012 | Assessment and rating of local sustainability focused on U.S. cities, covering broad sustainability aspects. | https://icleiusa.org/star-communities/ |
| UN-Habitat Global City Indicators Facility (GCIF) | 2008 | Provides a framework for cities to collect and monitor key indicators in the area of people, housing, economy, government, geography and climate | https://unhabitat.org/global-city-indicators-facility |
| UN HABITAT Global City Prosperity Iniitiative | 2012 | Index assessing urban prosperity in five areas called "the wheel of prosperity": productivity, infrastructure, quality of life, equity and social inclusion and environmental sustainability. | https://unhabitat.org/the-city-prosperity-initiative-brochure Reviewed by (Shmelev and Shmeleva, 2019) |
| China's Urban Sustainability Index | 2013 | Assesses the sustainability of Chinese cities based on five key indicators: basic needs, resource efficiency, environmental | https://coilink.org/20.500.12592/3z93vp (Columbia University, Tsinghua University and McKinsey & |

| Sustainable framework | Year | Short description | Author/ Reference |
| --- | --- | --- | --- |
| | | cleanliness, built environment and commitment to future sustainability. | Company, 2010) Reviewed by (Shmelev and Shmeleva, 2019) |
| World Cities Culture Forum Index | 2012 | Measures the cultural vibrancy and accessibility of cities. | www.worldcitiescultureforum.com/ |
| **2.b National Sustainability Indices:** | | | |
| UN SDG (Sustainable development goals) | 2015 | Also known as the Global Goals adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure peace and prosperity for all through 17 indicators. | https://sdgs.un.org/goals |
| University of Notre Dame Global Adaptation Initiative | 2015 | Assesses countries' and cities' vulnerability and readiness for climate change adaptation. | https://gain.nd.edu/ Reviewed by (Shmelev and Shmeleva, 2019) |

*Source: Author*

Despite extensive efforts to develop standardized sustainability criteria, existing frameworks often fail to align with local priorities. Many of them disproportionately emphasize environmental and economic dimensions while neglecting institutional and social drivers that shape municipal decision-making. Mori and Christodoulou (2012) critically examine major indices, including the Ecological Footprint (EF), Environmental Sustainability Index (ESI), and Human Development Index (HDI), identifying key shortcomings such as the lack of integration of the triple bottom line (environmental, economic, and social aspects), inadequate consideration of external impacts beyond city boundaries, and limited applicability across diverse urban contexts. This fragmented approach to sustainability assessment overlooks the underlying institutional and social factors that influence urban policy choices and fails to capture the full spectrum of benefits associated with sustainable actions. As a result, cities miss critical opportunities to optimize co-benefits beyond direct $CO_2$ reductions (Ryan and Campbell, 2012; Cluett and Amann, 2015; Rohde *et al.*, 2022). Without a comprehensive, multi-dimensional evaluation framework, decision-makers struggle to design policies that effectively leverage synergies between economic growth, environmental protection, and social equity (Mori and Christodoulou, 2012).

Developing universal sustainability criteria remains a challenge due to: (a) diversity of urban sustainability needs – What constitutes sustainable development varies across different cities and regions (Joss and Rydin, 2018); (b) data limitations – Most urban indicators rely on national or regional statistics, which do not always reflect city-level realities (Gazzo and Farhangi, 2014); and (c) interconnected sustainability dimensions – Traditional frameworks, that use either only environmental, economic, social, and occasionally institutional factors, often fail to capture synergies between mitigation and adaptation actions and are insufficient to capture the complex interconnections of urban sustainability (Cohen, 2017; Michalina *et al.*, 2021; Drastichová, 2023).

### 2.3.5 Preference Model – Weight Elicitation Methods

The preference model is a set of mathematical steps to uncover decision-makers values, often performed through a form of comparison between alternatives. Even when dealing with simpler models as is pairwise comparison, which are an underlying principle for many popular MCDA methods, the formula for calculating the number of independent pairwise comparisons is seen in **(1)**, where k is the number of conditions, or criteria. This means that if there were only six criteria by which the alternatives are compared, the number of independent comparisons would be fifteen.

$$\boldsymbol{k} \times (k - \mathbf{1}) \div \mathbf{2} \qquad (1)$$

In 1956, psychologist George Miller demonstrated that the capacity of human working memory is limited to approximately 7±2 units or bits or chunks of information, a concept now widely known as Miller's Theory (Miller, 1956). This finding underscores the significance of structuring and prioritizing ideas in complex scenarios. When applied to the domain of decision-making, the implication is clear: the presence of multiple criteria can lead to a proliferation of decisions or trade-offs, the comparison of which exceeds the processing capacity of human cognition when attempted solely in one's mind. This realization highlights the necessity for systematic approaches in handling multifaceted decision-making processes in the form of software. Cajot *et al.* (S. Cajot *et al.*, 2017; Sébastien Cajot *et al.*, 2017c) investigated the factors influencing policymakers' selection of specific MCDA methods in the context of urban energy systems. They discovered that the predominant reasons for choosing a particular method were their popularity or widespread usage, their intuitive or straightforward nature, and their capacity to integrate both qualitative and quantitative data.

While incorporating weighting subjectivity enables decision-makers to align projects with local priorities—thereby increasing the likelihood of implementation—it can also introduce distortions when compared to objective economic valuations. Consequently, financially unprofitable adaptation actions may appear more favourable when subjective priorities are emphasized. This effect is particularly relevant in sustainability planning, where most climate actions do not yield immediate financial returns unless future climate hazards are accounted for.

Once the criteria is set and the alternatives were chosen, a scoring of all actions against all criteria needs to be performed by all decision-makers. To be able to compare all the indicators across multiple categories or criteria and to aggregate results, they need to be "normalised" or transferred to a same scale.

### 2.3.6 Criteria Normalisation Techniques

There are different ways to normalize the values of each criterion to make them comparable by adjusting them to the same scale. For example, linear (either on a usual 0 to 1 scale, or on a preset min-max scale), vector, Z-score, log scaling, or clipping values at a predetermined minimum or maximum to handle outliers. Vafaei et *al.* (2016) recognize five common techniques, and describe their formulas:

**Table 9:** Common MCDA normalization techniques.

| Normalization technique | Condition of use | Formula |
|---|---|---|
| Linear: Max | Benefit criteria | $n_{ij} = \frac{r_{ij}}{r_{max}}$ |
| | Cost criteria | $n_{ij} = 1 - \frac{r_{ij}}{r_{max}}$ |
| Linear: Max-Min | Benefit criteria (LMI) | $n_{ij} = \frac{r_{ij} - r_{min}}{r_{max} - r_{min}}$ |
| | Cost criteria (SMI) | $n_{ij} = \frac{r_{max} - r_{ij}}{r_{max} - r_{min}}$ |
| Linear: sum | Benefit criteria | $n_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}}$ |

| | | |
|---|---|---|
| | Cost criteria | $n_{ij} = \frac{1/r_{ij}}{\sum_{i=1}^{m} 1/r_{ij}}$ |
| Enhanced accuracy | Benefit criteria | $n_{ij} = 1 - \frac{r_j^{max} - r_{ij}}{\sum_{i=1}^{m}(r_j^{max} - r_{ij})}$ |
| | Cost criteria | $n_{ij} = 1 - \frac{r_{ij} - r_j^{min}}{\sum_{i=1}^{m}(r_{ij} - r_j^{min})}$ |
| Vector normalization | Benefit criteria | $n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r^2{}_{ij}}}$ |
| | Cost criteria | $n_{ij} = 1 - \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r^2{}_{ij}}}$ |
| Logarithmic normalization | Benefit criteria | $n_{ij} = \frac{\ln(r_{ij})}{\ln(\prod_{i=1}^{m} r_{ij})}$ |
| | Cost criteria | $n_{ij} = \frac{1 - \frac{\ln(r_{ij})}{\ln(\prod_{i=1}^{m} r_{ij})}}{m-1}$ |

*Source: Vafaei et al., 2016*

**Linear Max normalization**: This technique is not standard, but a possible interpretation could be scaling the values with respect to the maximum value in the dataset.

**Max-Min normalization**: A specific case of linear normalization where the values are rescaled

**Linear Sum normalization**: This method involves dividing each value by the sum of all values, ensuring that the sum of all normalized values is 1.

**Vector normalization** involves dividing each criterion value by the magnitude of the vector formed by all the criteria values. It ensures that the normalized vector has a length of 1.

Linear normalization, also known as feature scaling, typically involves shifting and rescaling the range of features. The data is scaled to a fixed range – usually 0 to 1 or -1 to 1.

The most appropriate four main techniques for SAW method are vector, linear max-min, linear max and linear sum. In a study (Chakraborty and Yeh, 2007) investigating most suitable normalisation techniques decision-making frameworks, it was determined that vector normalization and linear scale transformation, also known as the max method, were particularly effective when dealing with decision-making scenarios that involve a limited set of options and where the attributes being measured vary widely in scale.

When using qualitative or linguistic terms to evaluate options, these terms also need to be translated into numbers, which is itself a normalisation process. However, not much attention is given to this implicit normalisation. There is recent research suggesting a novel normalization method would solve the problem of normalisation being (Pena, Nápoles and Salgueiro, 2022)

The next section will overview some of the important aspects of successful decision making for local sustainable planning, regardless of the chosen methodology, followed by a chapter describing most prevalent MCDA methods for sustainable planning.

## 2.4 Synthesis and Research Gap

The literature supports the hypothesis that decision-makers in the sustainability domain benefit from structured decision-making processes. There is growing interest in multicriteria decision analysis (MCDA) as a leading approach for addressing the complexities and uncertainties inherent in environmental projects, particularly those related to sustainable and renewable energy systems(Mardani *et al.*, 2016). However, urban sustainable planning—especially efforts that aim to integrate both mitigation and adaptation actions—still lacks a systematic, multidisciplinary, and participatory framework that incorporates quantifiable data where relevant.

Despite the broad range of MCDA methods available, their use in local sustainable planning remains limited due to persistent challenges. A major gap in the literature is the lack of integrated decision-making frameworks capable of addressing mitigation and adaptation simultaneously, which is essential for capitalizing on their potential synergies. Each component of sustainability presents its own difficulties, as mitigation and adaptation measures often span diverse sectors and involve multiple decision-making bodies—such as budget units or municipal departments—each with distinct priorities and criteria that must be reconciled within a unified planning process.

Urban sustainability planning is often hindered by sectoral silos, which limit collaboration and prevent cities from leveraging synergies across climate actions. Bai et al. (2016) identify six key barriers to adopting systemic urban planning, including a failure to recognise the systemic nature of cities, inadequate mental models, and insufficient decision-support systems that integrate both adaptation and mitigation. They argue that these challenges can be mitigated through more effective planning and decision-making, underpinned by broader scientific deliberation on the selection of sustainability metrics and the collection of relevant data. Addressing these challenges requires not only improved data collection and spatial disaggregation capabilities but also innovative methodologies that enhance cross-sectoral cooperation.

Another key challenge in sustainability planning is the effective utilisation of synergies in urban areas – often involving reducing energy and water use and enhancing climate resilience through greening initiatives (Nordic Council of Ministers, 2017) – which requires innovative planning and cross-sectoral collaboration, both of which are currently lacking in many cities (Landauer et al., 2015). The literature strongly supports the idea that both developed and developing countries need innovative, cross-sectoral, multi-criteria tools and methodology for both local synergistic planning (Landauer et al., 2015), as well as national reporting on sustainable actions (Martín-Ortega et al., 2024). Supporting this perspective, Yang et al. (2020) analysed synergies between SDG indicators across 66 countries and found significant variability in how trade-offs and synergies are managed. Their findings indicate that future policies must integrate SDG strategies with ecosystem-based solutions tailored to regional contexts. This reinforces the need for a value-driven framework that explicitly acknowledges regional differences in sustainability priorities and ensures that decision-making reflects local needs.

Existing examples of integrated energy and spatial planning (Giannouli *et al.*, 2018), and guidance like the European Commission's SECAP framework (Bertoldi, 2018) fall short in providing specific methodologies for recognising and accounting for synergies during decision-making processes. Some guidance focuses exclusively on prioritising adaptation (Covenant of Mayors for Climate & Energy EUROPE, 2016; Institute for Global Environmental Strategies, 2014), or mitigation actions (De Miglio et al., 2016; Drozdz, 2011; Mosannenzadeh et al., 2017), or both separately (IHS Erasmus University Rotterdam, UN-HABITAT and ICLEI World Secretariat, 2014), but comprehensive guidance that integrates both adaptation and mitigation actions remains insufficient. Additionally, there is no established methodology for the joint planning or prioritization of these synergies.

Similarly, while several decision-support tools for prioritising urban sustainability exist (Ernst and Blaha, 2016), many have critical limitations. Some, such as CLIMACT Prio (IHS Erasmus University Rotterdam, UN-HABITAT and ICLEI World Secretariat, 2014), treat mitigation and adaptation as separate domains, or are only focused on adaptation (URBANPROOF, 2018), failing to capture their potential synergies. Others, like PAPRIKA (Hansen and Ombler, 2008a), function as blank canvases for ranking actions but provide no predefined criteria, placing the full burden of decision-making on the user. Additionally, many existing tools—such as the EU City Calculator (n.d.), CURB (World Bank, 2017), Own Your SECAP (n.d.), C40 Cities Climate Leadership Group (2025) Adaptation and Mitigation Interaction Assessment (AMIA) tool, and NDC Partnership (n.d.) Strategic Mitigation Adaptation Resilience Tool (SMART) for Planning—focus predominantly on emission reduction targets and direct costs, without offering a structured approach for prioritising actions. Additionally, sector-specific tools like PrioritEE (Salvia *et al.*, 2021), focus on energy management but fail to cover the full scope of SECAPs or criteria beyond cost savings and $CO_2$ reductions. As a result**, e**xisting tools and frameworks fall short of the conceptual requirements of city sustainability planning; Mori & Christodoulou (2012) emphasize the need for comprehensive, multi-criteria approaches, while Simoes et al. (2019) highlight the importance of integrating both qualitative and quantitative indicators. A more comprehensive multiple-criteria framework is essential to accurately capture the complex priorities and trade-offs involved in urban sustainability planning (Theodorou, Florides and Tassou, 2010).

Finally, there is a growing demand for decision-support tools that assess future risks and facilitate precautionary decision-making for sustainability (Lehner et al., 2018). To address this, urban sustainability frameworks should balance standardized guiding principles with customizable indicators, allowing cities to tailor assessments to their unique local contexts (Cohen, 2017). A value-based approach is particularly recommended, as it recognises local specificities and leverages existing data to enhance decision-making.

A comprehensive review of methodologies, sustainability indices, and real-world applications highlights the need for a more holistic, value-driven decision-support tool that ensures cities can align their sustainability actions with both long-term climate goals and local priorities. In response to this gap, SYNERGISE+ was developed as a structured, multi-criteria framework, designed to facilitate evidence-based prioritization while addressing the inherent complexities of urban sustainability planning.

Additional critical issue is the availability and quality of data. Enhancing the ability to measure what is most crucial, or at least identifying the missing information, along with incorporating local values and perceptions, will significantly increase the likelihood of successful implementation. The proposed framework must strike a balance between complexity—necessary to address the broad scope of sustainability—and simplicity, to avoid overwhelming decision-makers. Additionally, for measures to be effectively implemented, the process must prioritize the inclusion of key stakeholders' opinions, including citizens and various city departments, ensuring that the decision-making process is both comprehensive and actionable.

Key themes and gaps recognized in the literature review related to sustainable decision-making in cities are:

1. Integrated Synergy Evaluation: Integration of Mitigation and Adaptation Strategies: Research suggests that there is often a lack of an integrated approach to sustainable decision-making which would consider all climate targets under the same planning process, which leads to inability to utilise synergies from adaptation and mitigation measures (i.e. economic savings and additional benefits that would become evident if the measures were considered as a part of the same planning process).
2. Decision Support Tools: The literature emphasizes the importance of decision support tools and frameworks to assist any decision-maker in making informed decisions, and the lack of a specific methodology applicable to a multidisciplinary area such as SECAP implementation in cities.

3. Data and Information Gaps: The availability and quality of data and information are common challenges in sustainable decision-making. Research focuses on addressing data gaps, improving data quality, and enhancing information sharing among stakeholders. With sustainable decision-making, quantification of non-monetary benefits is of a specific interest: Failure to quantify the additional benefits of sustainable actions, such as social and environmental impacts, is a recurrent gap in the literature. Researchers explore methodologies for valuing these benefits separately, but they are rarely integrated into a streamlined decision process.
4. Inclusivity and Stakeholder Engagement: Gaps are identified in the level of inclusivity and stakeholder engagement in common decision-making processes. The literature often discusses that the prerequisite for successful initiative implementation is to utilize a participatory approach that involves diverse stakeholders, including marginalized communities.
5. Long-Term vs. Short-Term Decision Horizons: Prevalent decision-making methods often face challenges related to balancing short-term priorities and long-term sustainability goals. Literature discusses the need for decision frameworks that consider both temporal dimensions.
6. Policy Implementation and Evaluation: There is often a gap between policy development and effective implementation. Researchers explore strategies to bridge this gap and evaluate the impact of sustainable policies and measures.
7. Decision Uncertainty and Risk Management: Sustainable decisions are inherently associated with uncertainty and risk. Literature examines methods for assessing, communicating, and managing uncertainty in decision-making processes.
8. Scale and Contextual Variations: Sustainable decision-making can vary significantly in different geographical, social, and economic contexts. Research explores how decision frameworks can be adapted to suit various scales and contexts.

Concretely, each of the eight literature gaps will be addressed as described in Table 10.

Table 10: Addressing literature gaps.

| # | Literature gap | How it will be addressed |
|---|---|---|
| 1 | Integration of Mitigation and Adaptation Strategies | |
| 1a | the adaptation is overlooked | Adaptation and mitigation will be considered as a part of the same process, with criteria used that highlight benefits (and hidden benefits) of both approaches to combating climate change. |
| 1b | inability to utilise | List of synergies from research will be connected with the most common actions from SECAPs in order to flag potential |

| | | |
|---|---|---|
| | adaptation and mitigation synergies | synergies in the decision-making framework and motivate cities to implement synergistic actions together. |
| 1c | having to repeat the stakeholder involvement for both processes | Stakeholder inclusion will be easier, and more complete, through a process that considers an index (two-level criteria) which evaluates both adaptation and mitigation actions. |
| 2 | Variety of decision support models and tools to choose from | Model fit matrix will be developed which will ensure that local and regional decision-makers can choose an appropriate MCDA method outside of the ones utilized in this research. |
| 3 | Data and information gaps | Although decision-makers are encouraged to enter quantitative data for each action for each of the 12 criteria (i.e. whether the measure has a highly negative, slightly negative, neutral, slightly positive or largely positive contribution to a certain criteria), the framework is primarily qualitative. The aim is to encourage users to assess even the information they might not have readily available, which can also enable cities to better understand the effect of additional, or sometimes hidden, benefits and to decide whether additional resources for actual measurements of effects would be justified. |
| 4 | Inclusivity and stakeholder engagement | Pairwise comparisons help in decreasing the cognitive load and avoiding biases through indirect elicitation of criteria. The transitivity and the accuracy of the simple pairwise method will be enabled through PAPRIKA online tool. |
| 5 | Long-term vs. short-term decision horizons | Combining adaptation and mitigation measures and making the time-horizon a boundary instead of a criterion will help in viewing the benefits of the actions in a comparable manner. Additionally, the decision-maker can view the time horizon, or any other limit, but this will not intervene with the list of optimal measures. |
| 6 | Policy implementation and evaluation | Having a tool that is easy to reiterate will help decision-makers bridge this gap and evaluate the impact of sustainable policies and measures with up-to-date information. |
| 7 | Decision uncertainty and risk management | In this framework, uncertainty and risk will be viewed as a boundary instead of a criterion. This will help in viewing the benefits of adaptation and mitigation actions in a comparable manner. |

| | | |
|---|---|---|
| 8 | Scale and contextual variations | In the ex-ante testing of the tool, urban areas of different size and climate zone will be considered to assess the effect using the tool would have on the implementation of their implemented plans (i.e. how would the adaptation measures rank with the mitigation measures when considered together, instead of separately, and whether there is any difference when it comes to population size, climate zone, or certain type of measures). |

*Source: Author*

This research reflects on the above gaps and aims to contribute to the field of urban sustainability by enhancing an MCDA methodology for prioritising SECAP actions. The enhanced methodology behind this framework improves the accuracy and efficacy of MCDA outcomes, by a novel approach that considers comprehensive benefits of both mitigation and adaptation actions, underpinned by an inclusive decision-making process which accounts for specific city preferences. This integrative and value-based approach aims to provide cities with a robust, methodologically sound pathway for selecting and prioritizing actions aligning with their unique sustainability objectives and constraints to ultimately ensure better chances for project implementation.

# 3. Methodology

After a comprehensive literature review identified the need for a qualitative, compensatory multi-attribute decision-making (MADM) model for sustainable action prioritization, including the structuring of an original sustainable action prioritization framework, SYNERGISE+ was developed (Dragović Matosović, 2024).

This section explains the methodological steps shown in **Figure 4**, and the framework is applied to three EU Cities' SECAPs to show whether it accurately reflects cities' implicit SECAP priorities, using case studies to determine how cities allocate resources.

The model uses AHP-inspired pairwise comparison to elicit decision-maker preferences and assign appropriate weights to each of the twelve criteria, and a Simple Additive Weighting method as described by Kurniawati et al. (2021) to calculate the final score per action. The choice of compensatory MCDA as a proper method was confirmed through Rowley et al. (2012) schematic workflow for sustainable analysts. Following this workflow confirmed that a Type 1 compensatory approach, specifically the Simple Additive Weighting (SAW) method, was appropriate for the SYNERGISE+ decision context. This choice is supported by the availability of cardinal scores, the feasibility of eliciting substitution-based weights from decision-makers, and the nature of the decision objective—to rank and prioritize actions based on overall sustainability performance. The compensatory logic was also deemed consistent with a weak sustainability interpretation, where trade-offs among criteria (e.g., cost vs. impact) are considered acceptable within stakeholder-defined preferences.

**Table 11:** Key methodological choices in SYNERGISE+ following Rowley et al. (2012) MCDA workflow.

| **Decision Point** (Rowley *et al.*, 2012) | SYNERGISE+ Response |
|---|---|
| Who is the decision-maker? | Local authority representatives and planning staff |
| Nature of alternatives? | SECAP mitigation and adaptation actions |
| Type of evaluation criteria? | Combination of quantitative and ordinal sustainability indicators |
| Are cardinal weights feasible? | Yes, via structured pairwise comparisons |
| Can criteria be traded off? (Compensability) | Yes, trade-offs are acceptable under weak sustainability |
| Preferred aggregation logic | Compensatory; SAW selected |

*Source: Author*

The criteria framework was designed to align with key best practices, drawing on established principles for designing effective sustainability indicator frameworks ((Dale and Beyeler, 2001; Mäkinen *et al.*, 2018)), ensuring it remains scientifically robust, policy-relevant, and practical for municipalities. The result is a comprehensive five-dimensional, 12-criteria index tailored to the needs of urban sustainable development, explained in the following subsection.

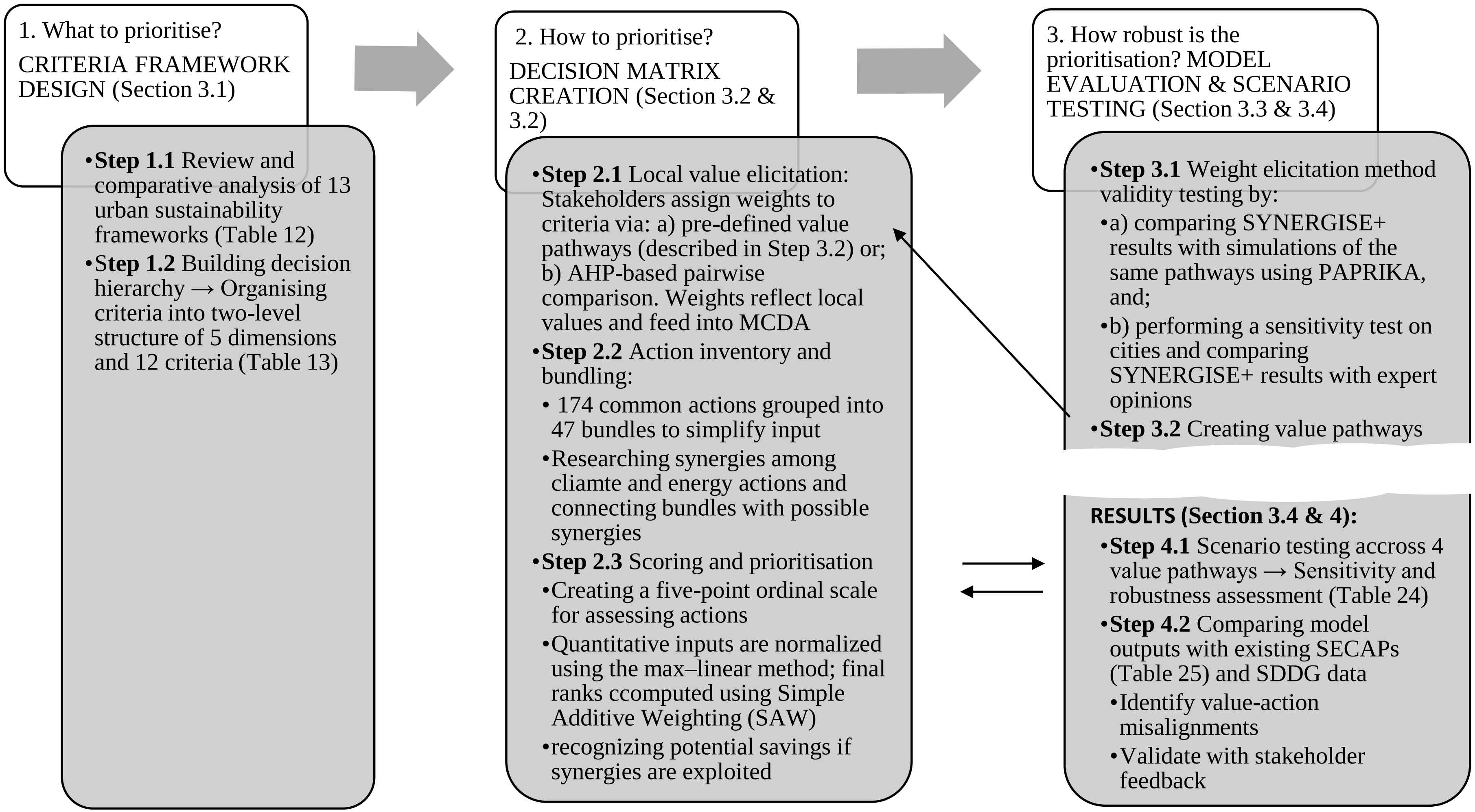



**Figure 4:** Overview of the SYNERGISE+ methodology, structured into three sequential phases: criteria design, decision matrix creation, and robustness evaluation. *Source: Author*

## 3.1 Design of the SYNERGISE+ Decision-Support Framework

### 3.1.1 Review and Comparative Analysis of 13 Existing Frameworks

To establish a robust evaluation structure for prioritising SECAP actions, first a systematic review and comparative analysis of 13 urban sustainability frameworks was conducted. This step was necessary to identify gaps, redundancies, and best practices across established methodologies and to assess the extent to which prevailing approaches incorporate multidimensional perspectives relevant to urban climate action planning. The aim was to validate the comprehensiveness and relevance of the SYNERGISE+ criteria while avoiding unnecessary duplication of indicators.

13 locally applicable indices—representing diverse analytical approaches, including climate action tracking, socioeconomic evaluation, and institutional governance assessment—were identified for systematic comparison. These indices were selected based on three main criteria:

- Comprehensiveness – Coverage of multiple sustainability dimensions (climate, economy, society, governance, and technology).
- Policy Alignment – Applicability within existing EU and global urban sustainability strategies.
- Decision-Support Usability – Established use in urban planning frameworks.

Table 12 presents the results of this comparative analysis, mapping how each SYNERGISE+ dimension and its associated criteria are represented (or underrepresented) in the reviewed frameworks. This mapping not only confirms the analytical validity of the SYNERGISE+ structure but also highlights key gaps in current assessment practices, particularly in relation to institutional capacity and technical feasibility—dimensions that are often overlooked in existing models.

Table 12: Comparative analysis of the SYNERGISE+ dimensions and evaluation criteria with 13 existing sustainable frameworks (refer to supplementary material for references and explanations).

| **SYNERGISE+ dimensions:** | **# of categories[(1)]** | **ENVIRONMENTAL IMPACT** | | | **ECONOMIC VIABILITY** | | | **SOCIAL EQUITY** | | **TECHNICAL FEASIBIL.** | | **INSTITUT. FRAMEWORK** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SYNERGISE+ criteria:** | 12 | Emission reduction and resource efficiency | Biodiversity conservation | Risk and vulnerability | Return on investment | Economic impact | Implementation and management | Equality /equity and accessibility | Quality of life and public health | Technological maturity and recycling potential | Innovation and learning potential | Political and legal framework | Political acceptability |
| **Existing frameworks:** | | | | | | | | | | | | | |
| CDP ICLEI Track | 20+ | 6+ | 3+ | 1+ | 2 | 3 | | | 4+ | | | 1 | |
| EBRD GCAP | 20 | 5 | 4 | 1 | 1 | 2 | | 3 | 3 | | | | 1 |
| ECPI | 14 | 1 | | | | 2 | 4 | | | | 7 | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EUGCI | 20+ | 14+ | 1 | 1 | | | | | 2 | 1 | | | 1 |
| InSMART FP7 | 13 | 1 | | | 2 | 1 | 2 | | 2 | 1 | 2 | 1 | 1 |
| Life SEC ADAPT | 11 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | | | | 1 |
| PROSPECT(2) | 34 | | | | | 9 | 9 | | | | 1 | 13 | 2 |
| RFSC | 30 | 5 | 2 | 2 | | 1 | 1 | 7 | 4 | | 5 | 3 | |
| SDG EU Cities | 15 | 1 | (2)(3) | 1 | | 1 | | 4 | 3 | | 2 | 3 | |
| SDEWES | 12 | 5 | 1 | 1 | | | | | 1 | 1 | 3 | | |
| Smart Florence Plan | 11 | 1 | 1 | 1 | | | 1 | 6 | 1 | | | | |
| Smart and Sus. City | 16 | 3 | 2 | | | 3 | | 1 | 2 | 3 | 2 | | |
| SSI | 20 | 5 | 5 | | 1 | 3 | | 3 | 2 | | | 1 | |

*(1) A plus sign (+) after the number of indicators/categories signifies that the listed category is not a singular, easily quantifiable indicator but rather a broader capacity-based classification, encompassing multiple interrelated factors rather than a single, straightforward metric.*

*(2) PROSPECT City Capability Assessment Framework measures broad capacities (such as public stance or efficiency of process for permits), not necessarily straightforward indicators, not action level criteria.*

*(3) As per Lafortune et al (2019), SDG 14 and 15 are not applicable to city context.*

Comparative analysis (Table 12: Comparative analysis of the SYNERGISE+ dimensions and evaluation criteria with 13 existing sustainable frameworks (refer to supplementary material for references and explanations).Table 12**Error! Not a valid bookmark self-reference.**) shows that assessment frameworks mostly account for three dimensions: environmental, economic and, to some extent, social, with limited emphasis on institutional capacity and technical feasibility of suggested actions. Further, they often feature overlapping indicators that fall under similar criteria. This redundancy can lead to an inflated perception of importance in certain areas, while other equally critical aspects of sustainability may be undervalued or overlooked.

The 13 indices vary in approach, with some relying on quantitative metrics (CDP ICLEI, ECPI, EUGCI, SDEWES, SSI), while others combine quantitative and qualitative assessments (InSMART, Life SEC ADAPT, PROSPECT, RFSC, SDG, Smart Florence Plan). The main similarity of all but SYNERGISE+ is that they are mostly scenario oriented, and do not track individual actions, but rather certain goal-oriented indicators. Only InSMART, SDEWES, and SSI explicitly use MCDA to evaluate multiple factors simultaneously, making them more effective for complex decision-making. While most indices provide structured, data-driven insights, those incorporating qualitative aspects offer a value-based perspective on urban sustainability, enabling decision-maker preferences.

RFSC (Cerema, 2016) presents the most similarities with SYENRGISE+ in terms of covering five dimensions and assisting holistic urban planning, however, it has a more traditional urban sustainability structure, while SYNERGISE+ is tailored for decision-making and prioritisation of SECAP actions. Whereas RFSC is a qualitative framework focusing only on available statistical data, SYENRGISE+ is a quantitative framework allowing for stakeholders' preferences and expert opinions where there is no data available. Additionally, like most of the other available indices, RFSC is a better choice for monitoring sustainable project progress, but it does not help in prioritising or choosing sustainable projects in the planning stage.

The EBRD Green City Action Plan (GCAP) methodology is another notable framework, crucial for cities aiming to access EBRD financing or seeking to understand and improve the environmental performance of urban development projects. As a standardized, data-driven tool grounded in the Pressure-State-Response (PSR) model, GCAP enables cities to assess their environmental status through a suite of 114 indicators—35 of which are core—and benchmark their performance against international norms. The methodology's sectoral focus on energy, water, transport, and land use supports the identification and prioritization of infrastructure investments that contribute to measurable sustainability improvements.

Despite their different origins and end goals, GCAP and the SYNERGISE+ methodology share several foundational principles. Both frameworks are structured, multi-dimensional tools aimed at improving urban sustainability planning. Each provides a pathway for prioritizing actions that respond to local environmental challenges while aligning with global agendas such as the Sustainable Development Goals (SDGs). Both methodologies value a comprehensive diagnostic phase, stakeholder involvement, and the integration of environmental, and, to somewhat degree, social and institutional dimensions. Moreover, each promotes a transition toward more sustainable urban systems through strategic planning and action-based implementation.

However, GCAP's focus on standardized benchmarking and infrastructure delivery reveals certain methodological gaps that SYNERGISE+ addresses. Unlike GCAP, SYNERGISE+ offers a participatory, value-based approach that embeds local stakeholder preferences directly into the prioritization of climate and sustainability actions. Additionally, it explicitly recognizes synergies between mitigation and adaptation measures, allowing for the identification of co-benefits that are often overlooked in infrastructure-centric planning. Furthermore, SYNERGISE+ integrates four additional non-financial benefits—implementation and management, technological maturity and recycling potential, innovation and learning potential, and political and legal framework—through a five-, instead of a three-dimensional multi-criteria framework. While GCAP is structured around sectoral assessments, SYNERGISE+ is project-focused, enabling cities to rank and select individual actions based on local priorities and context. Its emphasis on ex-ante evaluation and flexibility in decision-making enables more nuanced, context-sensitive planning, particularly in cities with complex governance environments or limited technical capacity. As such, SYNERGISE+ not only complements GCAP but also offers a valuable extension to its more technical and performance-based structure.

Although most indexes have three or four dimensions, SYNERGISE+ takes up the suggestion that SDGs should be disaggregated into four thematic areas for clarity—environmental, economic, social, and governance (Dang and Serajuddin, 2020). Additionally, a fifth thematic area (or dimension) is proposed to enhance understanding of countries' success—technical feasibility and competitiveness—proving it is crucial for comprehensive analysis, and a main differentiator in overall SDG performance.

### 3.1.2 Choosing Original Criteria and Dimensions

Based on this analysis, the SYNERGISE+ framework was developed, structured into five dimensions and twelve criteria (Table 13), reflecting the most recurrent and actionable priorities across reviewed frameworks. The framework is structured around a two-level hierarchy with five dimensions and 12 criteria, derived from a comparative analysis of leading sustainability indices.

The criteria are grouped into five key dimensions — environmental, economic, social, technical, and institutional — with each dimension represented by 2–3 operational criteria. This structure was designed to offer a holistic but decision-relevant view, covering not only climate impact and cost-efficiency but also action feasibility, stakeholder acceptance, and governance capacity. It was designed to align with key best practices, drawing on established principles for designing effective sustainability indicator frameworks (Mäkinen *et al.*, 2018) ensuring it remains scientifically robust, policy-relevant, and practical for municipalities.

Table 13: List of dimensions and criteria of the SYNERGISE+ sustainable index.

| No. | Dimensions | Criteria |
|---|---|---|
| A | ENVIRONMENTAL IMPACT | 1. Emission reduction and resource efficiency |
| | | 2. Biodiversity conservation |
| | | 3. Risk and vulnerability |
| B | ECONOMIC VIABILITY | 4. Return on investment |
| | | 5. Economic impact |
| | | 6. Implementation and management |
| C | SOCIAL EQUITY | 7. Equality /equity and accessibility |
| | | 8. Quality of life and public health |
| D | TECHNICAL FEASIBILITY & COMPETITIVENESS | 9. Technological maturity and recycling potential |
| | | 10. Innovation and learning potential |
| E | INSTITUTIONAL FRAMEWORK | 11. Political and legal framework |
| | | 12. Political acceptability |

The resulting criteria structure provided the analytical foundation for the SYNERGISE+ decision matrix and was applied across subsequent steps in the MCDA process.

### 3.2 Eliciting Values and Evaluating Actions

The evaluation process in SYNERGISE+ is structured around a transparent and participatory MCDA framework, guiding decision-makers through a logical sequence: from expressing value preferences, to scoring alternatives, to interpreting results under different scenarios. The following subsections detail the methodological components that underpin this evaluation framework.

#### 3.2.1 Value Preferences and Weighting via Pairwise Comparison

The model is fit for group decision making by allowing expression of preferences, which are then used to form weights for each of the criteria. This value preference elicitation is performed through pairwise comparisons of both first (the five dimensions) and second level criteria (12 criteria), asking the decision-maker to state which is preferred with a five-level preference scale (much more, more, equally, less, and much less important) (**Table 14**), and the weights are automatically created after answering 19 questions (*n(n-1)/2* unique comparisons) (**Table 15**). Pairwise comparison was chosen due to its ability to reduce cognitive bias and provide more consistent weight assignment, as opposed to direct ranking methods, which can be highly subjective, however, the five level preference scale is a variation of the classic nine intensities Saaty's AHP scale (Saaty, 1987, 1994), and it was chosen to lower the elicitation burden.

**Table 14:** Linguistic scale and Score index of the Pairwise Comparison of SYNERGISE+ sustainable framework.

| Linguistic Preference Scale | Score Index (*a*) | Reciprocal Value (*1/a*) |
|---|---|---|
| Much more important | 4 | 1 |
| More important | 3 | 2 |
| As important as | 2.5 | 2.5 |
| Less important | 2 | 3 |
| Much less important | 1 | 4 |

*Source: Author*

Each dimension weight is determined by:

$$W_i = \frac{\Sigma a_{ij}}{\Sigma \mathrm{A}} \qquad (1)$$

Where:

$W_d$ is the weight for the dimension.

$a_{ij}$ is the sum of all comparisons for dimension $d$.

ΣA is the total sum of the entire matrix.

The final weight for each criterion is given by multiplying the dimension weight by the criteria weight within that dimension:

$$W_t = W_c \times W_d \quad (2)$$

Where:

$W_t$ is the final absolute weight for each criterion.

$W_d$ is the weight of the dimension.

$W_c$ is the weight of the criterion within its dimension.

**Table 15:** Pairwise comparison matrix – a method for calculating the relative weight factor of each criterion.

**Calculation of weighting factor for each pairwise comparison component (dimension and criteria):**

| | Environmental impact | Economic viability | Social equity | Technical feasibility & competitiveness | Institutional framework | Dimension weight distribution ($W_d$) |
|---|---|---|---|---|---|---|
| Environmental impact | / | $a_{12}$ | $a_{13}$ | $a_{14}$ | $a_{15}$ | $\frac{\Sigma a_{1j}}{\Sigma A}$ |
| Economic viability | $1/a_{12}$ | / | $1/a_{23}$ | $1/a_{24}$ | $1/a_{25}$ | $\frac{\Sigma a_{2j}}{\Sigma A}$ |
| Social equity | $1/a_{13}$ | $1/a_{23}$ | / | $1/a_{34}$ | $1/a_{35}$ | $\frac{\Sigma a_{3j}}{\Sigma A}$ |
| Technical feasibility & competitiveness | $1/a_{14}$ | $1/a_{24}$ | $1/a_{34}$ | / | $1/a_{45}$ | $\frac{\Sigma a_{4j}}{\Sigma A}$ |
| Institutional framework | $1/a_{15}$ | $1/a_{25}$ | $1/a_{35}$ | $1/a_{45}$ | / | $\frac{\Sigma a_{5j}}{\Sigma A}$ |
| | | | | | | 100% |

| | Return on investment | Economic impact | Implementation and management | Criteria weight distribution per dimension (relative factor $W_c$) | Final criteria weight distribution (Absolute factor $W_t$) |
|---|---|---|---|---|---|
| Return on investment | / | $a_{12}$ | $a_{13}$ | $\frac{\Sigma a_{1j}}{\Sigma A_c}$ | $W_t = W_d \times W_c$ |
| Economic impact | 1/ $a_{12}$ | / | 1/ $a_{21}$ | $\frac{\Sigma a_{2j}}{\Sigma A_c}$ | |
| Implementation and management | 1/ $a_{13}$ | 1/ $a_{21}$ | / | $\frac{\Sigma a_{3j}}{\Sigma A_c}$ | |
| | | | | 100% | |

*Source: Author*

### 3.2.2 Scoring and Data Normalisation

Qualitative scoring of the alternatives is performed on a 5-level ordinal scale (large positive impact, small positive impact, no impact, small negative impact, large negative impact). The matrix score is calculated by using SAW, meaning the sum of multiplying each score with the criteria weights. Although compensatory approaches allow for value judgments through weight assignments, and are known to introduce biases that may ultimately alter decision- outcomes—one of the most significant challenges in MCDA (Riabacke, Danielson and Ekenberg, 2012b)—the compensatory SAW method was selected due to its computational simplicity and transparency in decision-making, making it suitable for municipal applications where decision-makers require easily interpretable results. SAW remains the predominant technique for prioritising alternatives across multiple criteria (Cloquell-Ballester *et al.*, 2007), even if it is frequently integrated with other methods, such as TOPSIS (Frieyadie, Sukmawati and Nurajijah, 2020), to enhance decision-making robustness.

Among normalization techniques, max-linear and vector normalization are considered the best fit for the SAW method (Chakraborty and Yeh, 2007). However, while **vector normalization** preserves relative proportions, it can amplify the impact of outliers, making it less robust in certain decision contexts. In contrast, **max-linear normalization** has been shown to provide the most consistent results and remains the most resistant to variations in criterion weights (Abdullah *et al.*, 2024), while vector normalization preserves relative proportions, it tends to amplify the impact of outliers. Given these advantages, the model employs **max-linear normalization** to integrate quantitative data into the response matrix, ensuring stability and comparability across criteria (Chakraborty and Yeh, 2007; Jahan and Edwards, 2015; Abdullah *et al.*, 2024). The max-linear normalization formula used is shown below (Chakraborty and Yeh, 2007):

$$n\_ij = x\_ij/x\_max \text{ for benefit criteria, and;} \tag{3}$$

$$n\_ij = 1 - x\_ij/x\_max \text{ for cost criteria;} \tag{4}$$

Where:

$n\_ij$ is the normalized value;

$x\_(i, j)$ is the original value, or performance rating of each criterion (*Cj*, *j* = 1,2, …, *n*)

$x\_max$ is the maximum performance rating among alternatives for attribute *Cj*.

### 3.2.3 Scenario Development and Result Interpretation

To understand city's implicit values, or their determination of success regarding different aspects of urban and local development results, four value-preference scenarios were created: (a) Balanced scenario, where all criteria are valued equally; (b) Conventional scenario, where political acceptability and Return on Investment (ROI) are given maximum weight, followed by balanced social equity, institutional framework and technological dimension, overlooking the biodiversity and risk and vulnerability impact, and; (c) Sustainable scenario, where the environmental goals and social wellbeing are paramount, regardless of the cost or necessary technology and legal changes to achieve them; (d) Extreme scenario, was additionally simulated for testing purposes to understand the maximum differences in weights that the model can create. It is assumed that cities thrive where they focus their attention and funds, thus scoring better in these dimensions.

**Table 16** indicates exact ranking and weights of each of the four scenarios.

**Table 16:** Simulation exercise of four predetermined scenarios in SYNERGISE+.

| | | **Balanced scenario** | | **Conventional scenario** | | **Sustainable scenario** | | **Extreme scenario** | |
|---|---|---|---|---|---|---|---|---|---|
| **Dimension** | **2nd level criteria** | Rank[1] | Weight | Rank | Weight | Rank | Weight | Rank | Weight |
| ENVIRONMENTAL IMPACT | Emission reduction and resource efficiency | 1 | 8.3% | 5 | 7.5% | 3 | 10.0% | 12 | 1.9% |
| | Biodiversity conservation | 1 | 8.3% | 11 | 3.3% | 3 | 10.0% | 8 | 4.7% |
| | Risk and vulnerability | 1 | 8.3% | 11 | 3.3% | 3 | 10.0% | 7 | 7.5% |
| ECONOMIC VIABILITY | Return on investment | 1 | 8.3% | 2 | 16.0% | 10 | 4.7% | 1 | 17.1% |
| | Economic impact | 1 | 8.3% | 4 | 8.0% | 10 | 4.7% | 4 | 10.7% |
| | Implementation and management | 1 | 8.3% | 10 | 6.0% | 10 | 4.7% | 9 | 4.3% |
| SOCIAL EQUITY | Equality /equity and accessibility | 1 | 8.3% | 6 | 7.0% | 1 | 14.0% | 2 | 13.0% |
| | Quality of life and public health | 1 | 8.3% | 6 | 7.0% | 1 | 14.0% | 2 | 13.0% |
| TECHNICAL FEASIBILITY | Technological maturity & recycling potential | 1 | 8.3% | 6 | 7.0% | 6 | 7.0% | 5 | 10.0% |
| | Innovation and learning potential | 1 | 8.3% | 6 | 7.0% | 6 | 7.0% | 5 | 10.0% |
| INSTITUTIONAL FRAMEWORK | Political and legal framework | 1 | 8.3% | 3 | 11.2% | 6 | 7.0% | 10 | 4.0% |
| | Political acceptability | 1 | 8.3% | 1 | 16.8% | 6 | 7.0% | 10 | 4.0% |
| | | | 100% | | 100% | | 100% | | 100% |

(1) The highest value is ranked 1st

*Source: Author*

The model evaluates how well each action aligns with the decision-maker's stated preferences by calculating a weighted score based on the 12 criteria. These weights are assigned according to the value elicitation process, ensuring that more important criteria have a greater influence on the final score. To determine which actions are most suitable, the model checks how many receive a score higher than 0.62 on a scale from 0 to 1. A score above 0.62 indicates that the action has an overall positive impact across all criteria, making it a strong candidate for implementation.

To evaluate the effectiveness of the SYNERGISE+ framework and the preset scenarios, the model was applied to three existing SECAPs and two model cities. The following section presents the findings of this application, assessing whether the framework successfully captures decision-making priorities and how different weighting scenarios influence action rankings**.**

### 3.3 Identifying Synergies Across Actions

One of the principal advantages of integrating mitigation and adaptation measures into a unified planning process lies in the ability to identify and leverage co-benefits and synergistic effects. While co-benefits refer to the shared or overlapping positive outcomes of two distinct actions, synergies arise when implementing two or more actions simultaneously yields a greater combined benefit than the sum of their individual effects. For instance, combining building insulation with green roofs creates a synergy where the installation of insulation improves the thermal efficiency of green roofs and vice versa—achieving enhanced outcomes at a potentially lower combined cost than implementing each independently.

Although quantifying such synergies remains methodologically complex and context-specific, the SYNERGISE+ tool is designed to flag action bundles with potential synergies. These bundles serve as a strategic entry point for further expert analysis. The process begins by compiling all relevant actions and clustering them into 47 actionable bundles. From these, the tool identifies 21 bundles with embedded synergy potential, based on sectoral overlap, temporal complementarity, and shared goals.

While the current study does not conduct quantitative synergy estimation, it lays the foundation for such assessments. By systematically organising and labelling synergistic actions, SYNERGISE+ helps local authorities prioritise areas where further evaluation may yield significant planning efficiencies and investment benefits. In this way, the methodology supports forward-looking governance, encouraging integrated climate action planning that goes beyond isolated mitigation or adaptation agendas.

Qualitative knowledge-structuring approach to develop a harmonised library of local climate and energy actions and to identify potential interactions between measures. The methodological process consisted of four main stages, as shown in Figure 1: (1) source identification, (2) action extraction and screening, (3) harmonisation and classification, and (4) qualitative identification of potential synergies among actions.

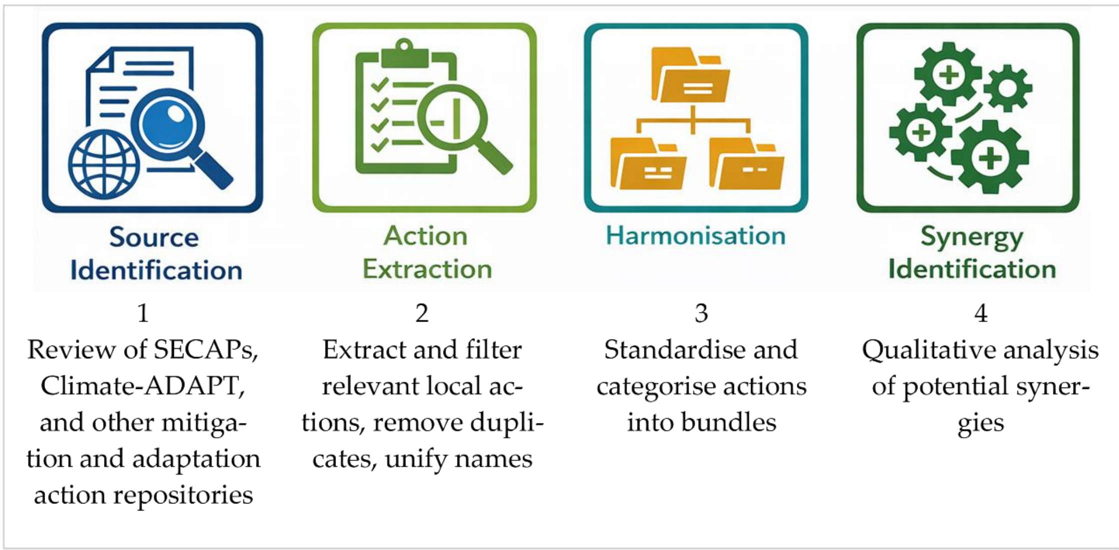



**Figure 5:** Development of the Climate–Energy Action Library.

The objective was to compile an exhaustive set of climate and energy actions documented in existing action libraries, guidance frameworks, and municipal plans, including a detailed review of European Sustainable Energy and Climate Action Plans (SECAPs) prepared under the Covenant of Mayors framework and widely used international repositories. During consolidation, duplicate or overlapping actions were harmonised and merged; however, the resulting Climate-Energy Action Library is intended to comprehensively cover the range of measures currently applied or recommended in local climate planning. While individual actions may be labelled differently across sources, all identified measures can be accommodated within the proposed classification structure.

### 3.3.1 Action Inventory and Thematic Clustering

The SYNERGISE+ tool was developed with the objective of integrating the most frequently employed actions from SECAPs. Consequently, it provides an extensive compilation comprising 58 adaptation actions, 116 mitigation actions, and two actions targeting energy poverty. Although there are only two action bundles aimed at energy poverty, this division was chosen to resemble the Covenant of Mayors reporting framework.

The source for adaptation actions is the European Climate Adaptation Platform Climate ADAPT (European Environment Agency and European Comission, 2016), a partnership between the European Commission and the European Environment Agency. The source for mitigation actions is CLIMACT Prio - a Capacity building and Decision Support tool (IHS Erasmus University Rotterdam, UN-HABITAT and ICLEI World Secretariat, 2014).

For enhanced user convenience and efficiency, these actions have been consolidated into 47 distinct action groups or bundles (detailed in Appendix E). This grouping facilitates quick and intuitive selection, enabling decision-makers to efficiently identify and include relevant SECAP actions.

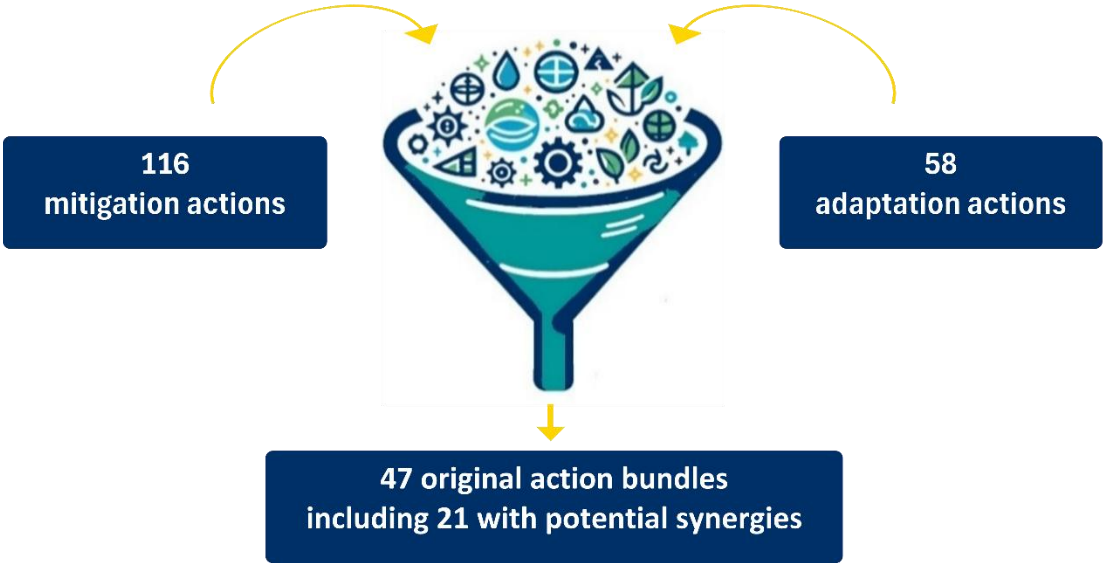



**Figure 6**: SYNERGISE+ bundles 174 climate actions into 47 groups, identifying 21 with synergy potential between mitigation and adaptation.
*Source: Author*

To support strategic planning and targeted decision-making, SYNERGISE+ enables the filtering of clustered actions based on three dimensions: **type of action**, **affected sectors**, and **climate hazards addressed**. This classification facilitates the identification of cross-sectoral impacts and synergies across adaptation and mitigation domains.

**Table 17**: Division of clustered actions by type, sector a, and climate impacts.

| **Type of action** | **Affected sectors** | **Climate impacts** |
|---|---|---|
| Awareness | Buildings (Buil) | Droughts (Dr) |
| Financial | DRR | Extreme Temperatures (ET) |
| Infrastructure | Energy (En) | Flooding (Fl) |
| Natural | Natural ecosystem (Nat) | Ice & Snow (I&S) |
| Policy | Transport (Tr) | Sea Level Rise (SLR) |
| Technological | Water & Waste (WW) | Storms (St) |
| | | Water Scarcity (WS) |

*Source: Author*

It is important to note that the SYNERGISE+ sectoral classification differs from that of the Global Covenant of Mayors (GCoM) Reporting Framework (Covenant of Mayors for Climate & Energy EUROPE, 2016). To ensure interoperability and facilitate reporting alignment, **Table 18**: Division of climate actions by sectors and climate impacts as per Covenant of Mayors Global Reporting Framework. **Table 18** presents the sector and hazard categorizations used by GCoM.

**Table 18**: Division of climate actions by sectors and climate impacts as per Covenant of Mayors Global Reporting Framework (Covenant of Mayors for Climate & Energy EUROPE, 2016).

| **GCoM sector division:** | **GCoM climate hazards:** | **GCoM impacted policy sectors:** |
|---|---|---|
| Municipal buildings, equipment/facilities | Extreme heat | Buildings |
| Tertiary buildings, equipment/facilities | Extreme cold | Transport |
| Residential buildings | Heavy precipitation (rainfall, snowfall, for, hail) | Energy |
| Public lighting | Floods | Water |
| Industry (incl. non-ETS) | Drought & water scarcity | Waste |
| Municipal fleet | Sea level rise | Land use planning |
| Public transport | Storms | Agriculture & forestry |
| Private and commercial transport | Mass movements (Rockfall /Landslides/ avalanche/rockfall) | Environment & biodiversity |
| Agriculture, forestry, fisheries | Forest and land fires | Health |
| Local electricity production | Others (including chemical change and biological hazards) | Civil protection & emergency |
| Local heat/cold production | | Tourism |
| Others | | Other |

*Source: Author*

The SYNERGISE+ tool, however, is designed to integrate mitigation and adaptation strategies, thus it does not separate actions into distinct mitigation and adaptation sectors. Instead, it emphasizes the synergistic potential of combining these approaches for comprehensive climate action planning and thus uses one sector division for all actions.

The affected sectors include the following:

- Buildings - includes regulation, awareness raising and construction of buildings & facilities in all sectors (public, commercial and residential), as well as RES solutions in buildings
- Disaster Risk Reduction (DRR) - aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development.
- Energy - all energy related actions including in industrial processes and product use, public lighting & traffic signals
- Natural ecosystem - encompasses actions in the agriculture, biodiversity, forestry and land use, marine, fisheries and aquaculture sectors
- Transport - includes transport and traffic management actions, from regulation to investments in low-carbon transport options
- Water and waste management - includes water related actions in all sectors, from agriculture to use of water in powerplants.

The sectors and climate impacts division are from Climate Adapt, considering that the actions offered are from their database. Sectors division for mitigation actions is from ClimAct Prio Tool and it is even more detailed in terms of the government sector. If the exact action isn't found, it is ok to choose a similar one, as long as all stakeholders using the tool understand what this action represents in their city.

Further, instead of dividing the sectors into public/private/commercial etc., It captures actions spanning six different types of sectoral actions: awareness raising, financial, infrastructure, natural, policy and technological actionsČ

Infrastructure - structural projects such as RES, buildings & facilities, transport. It includes new climate-resilient and efficient facilities, as well as existing building and facilities reinforcements, energy efficient refurbishment, floodwalls, earthquake-resistant construction, and fire-resistant materials.

- Natural - natural systems protection aim to preserve or restore natural ecosystems and processes to reduce the vulnerability of communities to hazards.
- Policy - policy, planning and governance actions focus on establishing laws, regulations, and institutional frameworks to promote energy savings, hazard resilience and disaster risk reduction.
- Awareness - awareness and public education campaigns

- Technological - technological solutions (other than RES) incl. public lighting. Use of advanced tools and technologies to enable better control of CO2 emissions (such as smart meters, smart homes, lighting regulation etc.), or adaptation solutions which predict, detect, and respond to hazards more effectively (such as remote sensing, Geographic Information Systems (GIS), weather forecasting models, and hazard monitoring systems).
- Financial - financial and economic incentives and disincentives include strategies to allocate resources, incentivize risk reduction, and provide financial assistance to affected populations. Examples include feed-in-tariffs or disaster recovery funds, risk transfer mechanisms (e.g., insurance, reinsurance), microfinance programs, and incentives for investment in resilient infrastructure.

### 3.3.2 Recognition of Potential Synergies

Synergies between climate actions represent an important yet often underutilized opportunity in integrated planning. While the exact magnitude of synergistic effects is context-dependent and may not always be precisely quantifiable, recognizing their presence enables more strategic investment decisions. In the SYNERGISE+ model, synergy potential is flagged at two levels: within individual action bundles and across different bundles.

The synergy logic used in SYNERGISE+ is informed by an extensive meta-analysis of climate action synergies conducted by Sharifi (Sharifi, 2021). The findings from this study—summarized in **Table 20**—highlight combinations of mitigation and adaptation actions that frequently reinforce each other either operationally, financially, or in terms of outcome effectiveness. These combinations were mapped onto the SYNERGISE+ framework to identify actions where mutual implementation is likely to yield added value.

To operationalize this, SYNERGISE+ incorporates a synergy-flagging system in Step 6 of the tool. Each of the 47 action bundles contains a structured description and, where applicable, highlights:

- Intra-bundle synergies, where multiple actions grouped in the same bundle reinforce each other;
- Cross-bundle synergies, which suggest valuable pairings between actions from different bundles.

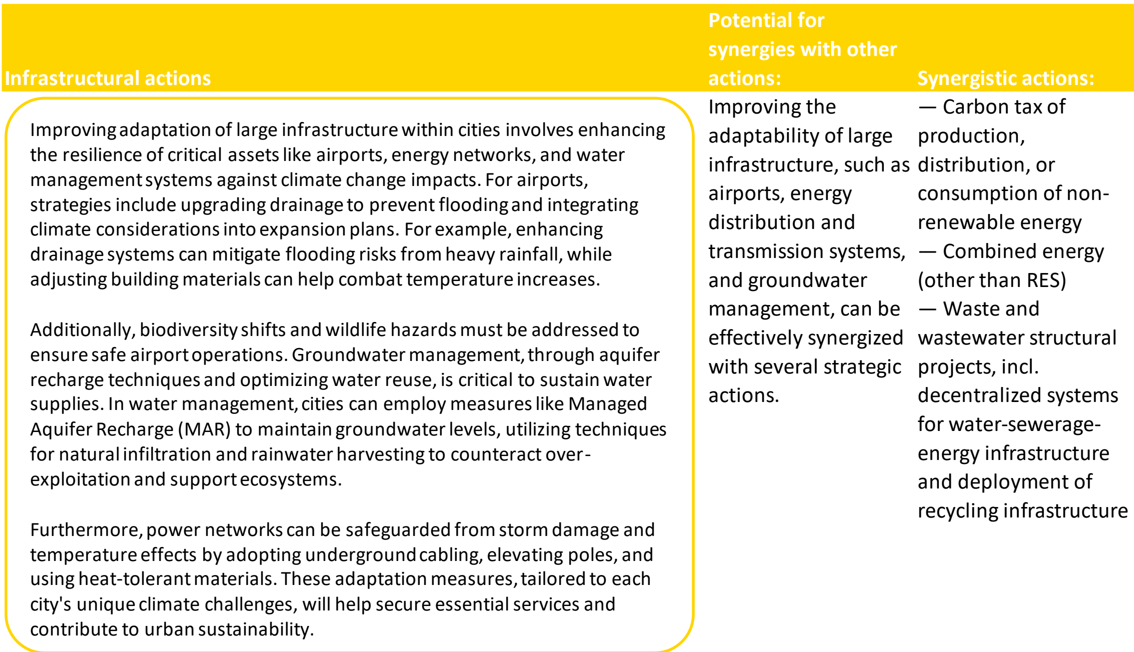
**Table 19:** Summary of synergy types identified in SYNERGISE+, including definitions, practical examples, and implications for integrated planning.

| Synergy Type | Definition | Example | Planning Implication |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Intra-Bundle Synergy | Synergies occurring between actions grouped within the same action bundle in SYNERGISE+, often due to functional or sequential complementarity. | Building insulation and green roofs within the 'Energy Efficiency in Buildings' bundle. | Encourages holistic consideration of actions within a single intervention area to maximize returns. |
| Cross-Bundle Synergy | Synergies occurring between actions in different bundles, where coordinated implementation enhances performance, reduces costs, or improves feasibility. | Passive building design from one bundle and smart metering systems from another bundle. | Promotes cross-sector coordination and scheduling to capture system-wide efficiencies and shared benefits. |

*Source: Author*

This information is not intended to be reviewed exhaustively, rather serves as a dynamic lookup feature to support decision-makers when considering a specific action. For each bundle, links to detailed descriptions and synergy suggestions are provided via the online SYNERGISE+ interface (see **Figure 7**).



| Infrastructural actions | Potential for synergies with other actions: | Synergistic actions: |
|---|---|---|
| Improving adaptation of large infrastructure within cities involves enhancing the resilience of critical assets like airports, energy networks, and water management systems against climate change impacts. For airports, strategies include upgrading drainage to prevent flooding and integrating climate considerations into expansion plans. For example, enhancing drainage systems can mitigate flooding risks from heavy rainfall, while adjusting building materials can help combat temperature increases.<br><br>Additionally, biodiversity shifts and wildlife hazards must be addressed to ensure safe airport operations. Groundwater management, through aquifer recharge techniques and optimizing water reuse, is critical to sustain water supplies. In water management, cities can employ measures like Managed Aquifer Recharge (MAR) to maintain groundwater levels, utilizing techniques for natural infiltration and rainwater harvesting to counteract over-exploitation and support ecosystems.<br><br>Furthermore, power networks can be safeguarded from storm damage and temperature effects by adopting underground cabling, elevating poles, and using heat-tolerant materials. These adaptation measures, tailored to each city's unique climate challenges, will help secure essential services and contribute to urban sustainability. | Improving the adaptability of large infrastructure, such as airports, energy distribution and transmission systems, and groundwater management, can be effectively synergized with several strategic actions. | — Carbon tax of production, distribution, or consumption of non-renewable energy<br>— Combined energy (other than RES)<br>— Waste and wastewater structural projects, incl. decentralized systems for water-sewerage-energy infrastructure and deployment of recycling infrastructure |

**Figure 7**: Example of a description of an action bundle from SYNERGISE+, identifying synergy opportunities within (first columns) and across bundles (the last column).
*Source: Author. Exhaustive list is available in the online version of the SYNERGISE+ tool (PROSPECT+, 2023).*

The bundles resulted in mostly policy (14) and natural (10) interventions, and the final division by intervention type is shown in **Figure 8**.

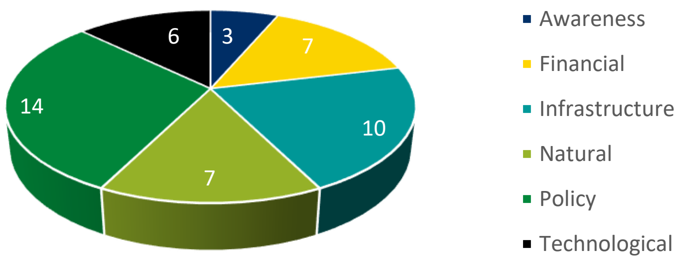



**Figure 8**: SYNERGISE+ library intervention type division.

The bundles were additionally divided by whether they fit into mitigation, adaptation, or both (**Figure 9**).

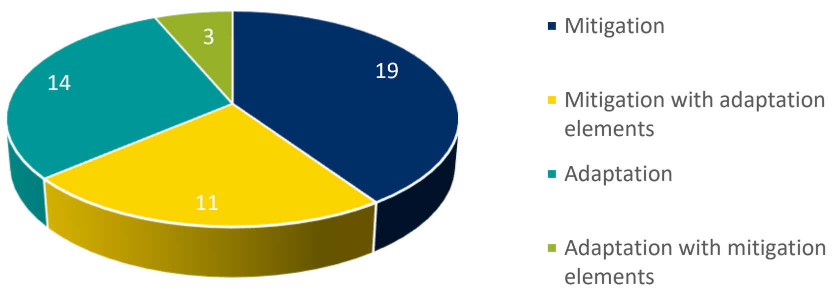



**Figure 9:** Type of intervention of the total 47 bundles.

While the aim of this study is not to quantify synergy savings, the tool provides a foundation for such calculations, as described in Section 3.3.3. Users are encouraged to use the synergy flags as a prompt to:

- Investigate technical or financial feasibility of combined implementation;
- Align implementation timelines to benefit from shared infrastructure;
- Engage stakeholders across departments/sectors to co-plan synergistic actions.

A full list of synergy pairs from Sharifi (2021), available in the online SYNERGISE+ tool step 6, links directly to this reference dataset for further exploration.

**Table 20**: Mitigation and adaptation synergies cross-reference from a recent meta study.

| # | Action 1 | Action 2 | Primary synergy | Cross-sectoral |
|---|---|---|---|---|
| 1 | Appropriate levels of density | Land use mix | Mitigation | No |
| 2 | Appropriate levels of density | Distribution and decentral. of energy systems | Mitigation | Yes |
| 3 | Appropriate levels of density | Transit-oriented development | Mitigation | Yes |
| 4 | Appropriate levels of density | Nature conservation/protection | Adaptation | Yes |
| 5 | Appropriate levels of density | Infill and brownfield (re-)development | Mitigation | Yes |
| 6 | Appropriate levels of density | Improved physical accessibility | Mitigation | No |
| 7 | Appropriate levels of density | Risk zoning policy | Adaptation | No |
| 8 | Appropriate levels of density | Relocation to avoid risk-prone areas | Adaptation | No |
| 9 | Appropriate levels of density | Improved connectivity | Mitigation | No |
| 10 | Appropriate levels of density | Promotion of low-carbon public transportation systems | Mitigation | Yes |
| 11 | Green roof, roof gardens, green façade | Building insulation | Mitigation | Yes |
| 12 | Green roof, roof gardens, green façade | Rainwater harvesting | Adaptation | Yes |
| 13 | Green roof, roof gardens, green façade | Urban agriculture | Adaptation | No |
| 14 | Green roof, roof gardens, green façade | Building codes | Mitigation | Yes |
| 15 | Green roof, roof gardens, green façade | Cool roofs and pavements (albedo enhancement) | Adaptation | Yes |
| 16 | Green roof, roof gardens, green façade | Xeriscaping | Adaptation | No |

| | | | | |
|---|---|---|---|---|
| 17 | Green roof, roof gardens, green façade | Distribution and decentralization of energy systems | Mitigation | Yes |
| 18 | Passive urban design | Cool roofs and pavements (albedo enhancement) | Adaptation | No |
| 19 | Land use mix | Transit-oriented development | Mitigation | Yes |
| 20 | Land use mix | Improved physical accessibility | Mitigation | No |
| 21 | Land use mix | Improved connectivity | Mitigation | No |
| 22 | Building insulation | Building codes | Mitigation | Yes |
| 23 | Building insulation | Passive building design | Mitigation | No |
| 24 | Building insulation | Building retrofit | Mitigation | Yes |
| 25 | Building insulation | Building energy efficiency improvement | Mitigation | No |
| 26 | Building insulation | Material durability improvement | Mitigation | No |
| 27 | Building energy efficiency improvement | Green building programs | Mitigation | No |
| 28 | Building energy efficiency improvement | Passive building design | Mitigation | No |
| 29 | Building energy efficiency improvement | Building retrofit | Mitigation | No |
| 30 | Building energy efficiency improvement | Building codes | Mitigation | Yes |
| 31 | Building energy efficiency improvement | Passive urban design | Mitigation | Yes |
| 32 | Green building programs | Building retrofit | Mitigation | No |
| 33 | Distribution and decentralization of energy systems | Waste to energy | Mitigation | Yes |
| 34 | Distribution and decentralization of energy systems | Diversified energy profile based on renewable energies | Mitigation | No |

| | | | | |
|---|---|---|---|---|
| 35 | Distribution and decentralization of energy systems | Electrification of urban transportation | Mitigation | Yes |
| 36 | Distribution and decentralization of energy systems | Energy storage systems | Mitigation | No |
| 37 | Energy storage systems | Electrification of urban transportation | Mitigation | Yes |
| 38 | Promotion of low-carbon public transportation systems | Adoption of high occupancy vehicle lanes | Mitigation | No |
| 39 | Promotion of low-carbon public transportation systems | Transit-oriented development | Mitigation | No |
| 40 | Promotion of low-carbon public transportation systems | Improved physical accessibility | Mitigation | Yes |
| 41 | Promotion of low-carbon public transportation systems | Improved connectivity | Mitigation | Yes |
| 42 | Promotion of low-carbon public transportation systems | Congestion pricing | Mitigation | No |
| 43 | Promotion of low-carbon public transportation systems | Vehicles and fuel tax policies | Mitigation | No |
| 44 | Promotion of low-carbon public transportation systems | Electrification of urban transportation | Mitigation | No |
| 45 | Promotion of low-carbon public transportation systems | Transportation demand management | Mitigation | No |
| 46 | Promotion of low-carbon public transportation systems | Parking demand management | Mitigation | No |
| 47 | Promotion of low-carbon public transportation systems | Infill and brownfield (re-)development | Mitigation | Yes |
| 48 | Promotion of low-carbon public transportation systems | Urban greening | Mitigation | Yes |
| 49 | Promotion of low-carbon public transportation systems | Land use mix | Mitigation | Yes |
| 50 | Promotion of Non-motorized transport infrastructure | Passive urban design | Mitigation | Yes |

| | | | | |
|---|---|---|---|---|
| 51 | Transportation demand management | Transit-oriented development | Mitigation | No |
| 52 | Transportation demand management | Congestion pricing | Mitigation | No |
| 53 | Transportation demand management | Parking demand management | Mitigation | No |
| 54 | Transportation demand management | Vehicle emissions rating | Mitigation | No |
| 55 | Parking demand management | Transit-oriented development | Mitigation | No |
| 56 | Vehicles and fuel tax policies | Congestion pricing | Mitigation | No |
| 57 | Vehicles and fuel tax policies | Transportation demand management | Mitigation | No |
| 58 | Passive building design | Green building programs | Mitigation | No |
| 59 | Passive building design | Building retrofit | Mitigation | No |
| 60 | Passive building design | Passive urban design | Mitigation | Yes |
| 61 | Urban agriculture | Waste to energy | Mitigation | Yes |
| 62 | Urban agriculture | Dietary changes | Mitigation | Yes |
| 63 | Urban agriculture | Wastewater recycling | Adaptation | Yes |
| 64 | Urban agriculture | Rainwater harvesting | Adaptation | Yes |
| 65 | Urban agriculture | Site level composting | Adaptation | Yes |
| 66 | Wastewater recycling | Rainwater harvesting | Adaptation | Yes |
| 67 | Urban greening | Xeriscaping | Adaptation | No |
| 68 | Improved physical accessibility | Transit-oriented development | Mitigation | Yes |
| 69 | Improved physical accessibility | Improved connectivity | Mitigation | No |
| 70 | Urban greening | Wetlands and water bodies | Adaptation | No |

| | | | | |
|---|---|---|---|---|
| 71 | Urban greening | Passive building design | Adaptation | Yes |
| 72 | Urban greening | Risk zoning policy | Mitigation | Yes |
| 73 | Urban greening | Stormwater management | Adaptation | Yes |
| 74 | Urban greening | Promotion of Non-motorized transport infrastructure | Mitigation | Yes |
| 75 | Urban greening | Water-sensitive urban design | Adaptation | Yes |
| 76 | Urban greening | Nature conservation/protection | Adaptation | Yes |
| 77 | Urban greening | Passive urban design | Adaptation | No |
| 78 | Urban greening | Cool roofs and pavements (albedo enhancement) | Adaptation | No |
| 79 | Nature conservation/protection | Xeriscaping | Adaptation | No |
| 80 | Water-sensitive urban design | Cool roofs and pavements (albedo enhancement) | Adaptation | Yes |
| 81 | Water-sensitive urban design | Rainwater harvesting | Adaptation | Yes |
| 82 | Environmental pricing and regulation | Congestion pricing | Mitigation | Yes |
| 83 | Environmental pricing and regulation | Vehicles and fuel tax policies | Mitigation | Yes |
| 84 | Passive building design | Building codes | Mitigation | No |
| 85 | Green building programs | Building codes | Mitigation | No |
| 86 | Slum upgrading | Building retrofit | Adaptation | Yes |
| 87 | Slum upgrading | Risk zoning policy | Adaptation | Yes |
| 88 | Risk zoning policy | Nature conservation/protection | Adaptation | Yes |
| 89 | Smart city plans | Car sharing | Mitigation | Yes |

| | | | | |
|---|---|---|---|---|
| 90 | Smart city plans | Transportation demand management | Mitigation | Yes |
| 91 | Smart city plans | Parking demand management | Mitigation | Yes |
| 92 | Smart city plans | Distribution and decentralization of energy systems | Mitigation | Yes |
| 93 | Smart city plans | Building energy efficiency improvement | Mitigation | Yes |
| 94 | Energy production and consumption monitoring | Building energy efficiency improvement | Mitigation | Yes |
| 95 | Energy production and consumption monitoring | Green building programs | Mitigation | Yes |
| 96 | Water demand management | Water efficiency improvement | Adaptation | No |
| 97 | Water-sensitive urban design | Water demand management | Adaptation | No |
| 98 | Water-sensitive urban design | Water efficiency improvement | Adaptation | No |
| 99 | Wastewater recycling | Water efficiency improvement | Adaptation | No |
| 100 | Water efficiency improvement | Rainwater harvesting | Adaptation | No |

*Source: Sharifi, 2021*

### 3.3.3 Estimating Synergistic Benefits

To support decision-makers in assessing the added value of combining climate actions, this study proposes a conceptual formula for estimating potential synergy savings. The formulation integrates cost efficiencies and performance enhancements derived from joint implementation. It is constructed as a synthesis of established approaches in cost-benefit analysis (CBA), multi-criteria decision analysis (MCDA), and systems thinking. The cost savings component reflects standard marginal cost comparison methods used in life-cycle costing and public infrastructure planning (GIZ, 2015). The performance gain component draws on systems theory and MCDA literature, where the combined effect of actions may exceed the sum of their individual impacts (Riabacke, Danielson and Ekenberg, 2012b; Sharifi, 2021). To account for the value of non-monetary co-benefits, a shadow pricing coefficient (θ theta) is introduced, consistent with practices in climate economics and integrated assessment models (Stern, 2008; OECD, 2015; Watkiss, 2015).

The resulting formula offers a flexible decision-support tool that can be adapted for further expert analysis, scenario modelling, or participatory evaluation.

This framework does not claim to provide exact savings values but serves as a strategic orientation tool, enabling local governments and planners to prioritize synergistic investments. Estimating the financial, environmental, or social value of synergies requires a more detailed, context-specific cost-benefit analysis that considers:

- Temporal alignment of actions (e.g., sequencing infrastructure upgrades to maximize compatibility).
- Cost-efficiency gains, such as shared labour, materials, or administrative procedures.
- Systemic interactions, where one action enhances the effectiveness of another (e.g., stormwater capture improving insulation performance).
- Avoided costs, such as reduced vulnerability or deferred infrastructure investment.

For each of the 21 identified synergistic bundles, savings could be estimated through scenario modelling, stakeholder interviews, or life-cycle costing techniques. Key indicators for estimating synergy savings may include:

- Reduction in total implementation costs (compared to sequential or stand-alone deployment),
- Decrease in project delivery time,
- Enhanced performance outcomes (e.g., energy savings, resilience),
- Increase in institutional or public support due to multi-benefit framing.

A proposed calculation for estimating synergy savings includes three formulas:

1. **Cost savings** – which represents the reduction in cost when actions are implemented together rather than separately. It can also include qualitative factors, such as increased public acceptance, faster implementation etc;

$$S_C = (C_A + C_B) - C_{AB} \tag{5}$$

Where:

$S_C$ = Cost savings from joint implementation

$C_A$ = Cost of implementing action A independently

$C_B$ = Cost of implementing action B independently

$C_{AB}$ = Cost of implementing actions A and B jointly (bundled)

2. **Performance gain** – which captures the added performance (e.g., efficiency, resilience, emission reductions) resulting from the synergistic interaction.

$$S_P = P_{AB} - (P_A + P_B) \tag{6}$$

Where:

$S_P$ = Performance gain from synergy

$P_A$ = Performance score or impact value of action A, across all five dimensions

$P_B$ = Performance score or impact value of action B, across all five dimensions

$P_{AB}$ = Performance score of joint implementation of A and B

3. **Total savings** – Finally, the total synergy savings is a combination of cost savings combined with performance gain multiplied by a coefficient converting performance gains to monetary value (based on valuation of energy saved, emissions reduced, resilience increased, etc.).

$$S_T = S_C + (\theta \times S_P) \tag{7}$$

Where:

$S_T$ = Total synergy savings (monetized)

$S_C$ = Cost savings from joint implementation

$S_P$ = Performance gain from synergy

$\theta$ = a coefficient converting performance gains to monetary value (based on valuation of energy saved, emissions reduced, resilience increased, etc.).

An example application, if insulating a building costs €30,000 and installing a green roof costs €40,000 separately, but jointly costs €60,000, is as follows:

$$S_C = (30{,}000 + 40{,}000) - 60{,}000 = €10{,}000 \tag{8}$$

If combined implementation improves energy efficiency by 20% more than the sum of both individually:

$$S_P = 0.20 \tag{9}$$

Assuming €1,000 value per 1% of added efficiency:

$$S_T = 10{,}000 + 10{,}000 \times 0.20 = €10{,}200 \quad (10)$$

Future application of SYNERGISE+ in real-life planning settings may integrate such assessments, ideally in collaboration with engineering, finance, and urban development experts. By highlighting where potential synergies exist, SYNERGISE+ serves as a decision-support layer guiding attention toward high-potential synergy bundles that would benefit from a deeper analysis.

## 3.4 Aligning the SYNERGISE+ Criteria Framework with the SDG Agenda

### 3.4.1 Typology and Data Sampling of SDG EU City 2019 Prototype Data

This study utilizes both the latest country-level SDG progress (2024 World SDG Index) (Sachs, Lafortune and Fuller, 2024) and city-level data from the 2019 EU Cities SDG Index SDGs (Lafortune *et al.*, 2019). While SDG data is updated annually at the national level, city-level SDG data was only collected once, in 2019, for 45 European cities as a prototype initiative. Despite its earlier date, the 2019 city dataset remains valuable for analysing patterns in how cities prioritize sustainable development dimensions and how these patterns compare with national trends. The methodology consists of three key steps:

1. Conceptualizing the SDGs within SYNERGISE+ Framework: The 17 SDGs are mapped into the five dimensions of SYNERGISE+—environmental, economic, social, technical, and institutional—by averaging the scores of relevant SDGs under each dimension.
2. Integrating SDG Scores into SYNERGISE+: The SYNERGISE+ framework is applied to:
    a. 167 countries from the 2024 World SDG Index (covering all 17 SDGs).
    b. 45 European cities from the 2019 EU Cities SDG Index (covering 15 SDGs). The 45 cities represent mainly the largest European Union urban centres, including all 27 capitals, and then additionally three cities outside of the EU; Oslo, Zurich, and London. Although the city dataset predates the country dataset, its inclusion is essential for examining value-based patterns in city performance and to unveil if there are patterns in the way cities implement sustainable goals.
3. Scoring and Analysis: Each SDG score is assigned to the most appropriate SYNERGISE+ dimension, then averaged within that dimension to create composite scores. The analysis assumes that cities and countries perform best in dimensions they prioritize. Based on that prioritization, the results are classified into four value-based scenarios: balanced, sustainable, technocratic, and conventional.

The SDG Index is primarily country-based and updated annually. In contrast, a single pilot application of the SDG framework at the city level was conducted in 2019, covering

45 European cities. This study therefore combines the most recent country-level SDG data with the available city-level data from 2019. Although the city dataset is dated, it remains valuable for identifying patterns in how cities prioritize sustainability dimensions and for assessing the extent to which these patterns align with or diverge from national trends.

The following graph shows their typology based on population, GDP, and SDG scores (circle size). Colour indicates the region city belongs to.

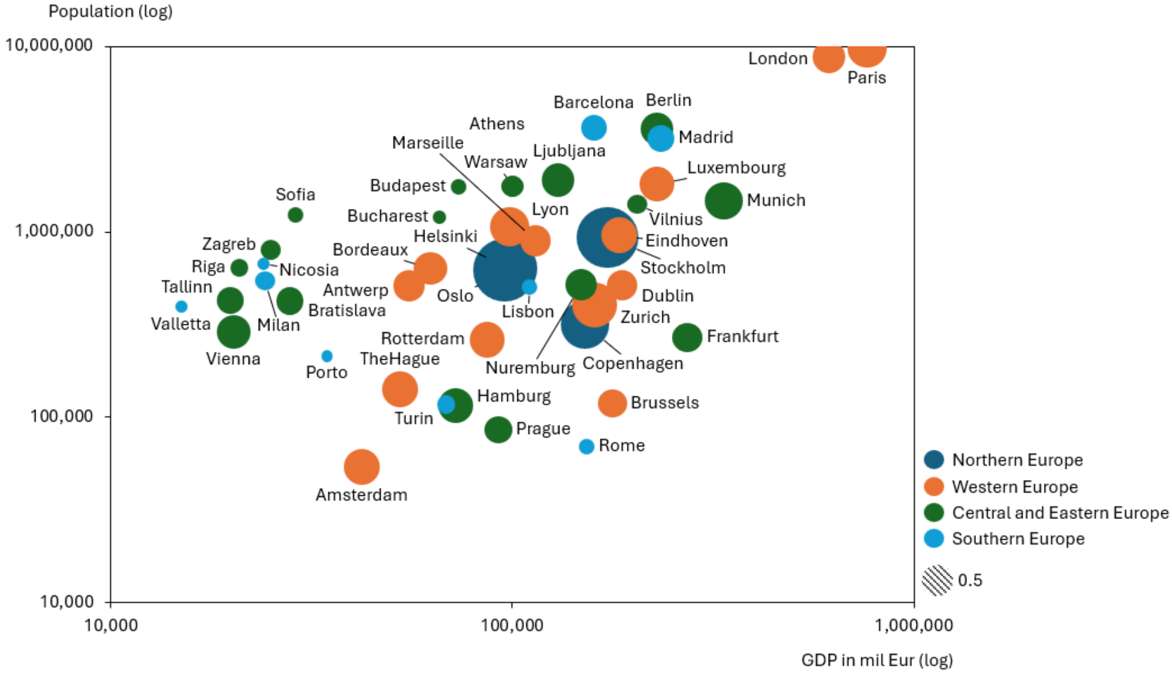



**Figure 10:** Typology of SDG EU cities 2019 prototype data. Axis labels represent population (logarithmic scale), and GDP (logarithmic scale), colour represents regions and circle size represents SDG score (the higher the score, the bigger the circle).
*Source: Author*

It is obvious that cities with higher GDP, such as Copenhagen, Zurich, Oslo, Stockholm, tend to have higher SDG Scores. However, some high-GDP cities, such as Frankfurt, Brussels, and Warsaw have relatively high GDP but moderate SDG scores, suggesting that economic strength alone does not always translate into sustainability.

There are obvious regional patterns in economic and sustainability Performance:

- Northern European cities (dark blue) generally show higher GDP and higher SDG scores
- Western European cities (orange) have a mix of both high- and mid-range GDP but still perform relatively well on SDGs.
- Central & Eastern European cities (green) and Southern European cities (light blue) tend to cluster towards lower GDP and lower SDG scores.

Large population cities, such as London, Paris, and Berlin do not necessarily have the highest SDG scores. Some smaller cities with high GDP (e.g., Zurich, Luxembourg, Copenhagen) perform better in SDGs, showing that population size alone does not guarantee sustainability success.

Southern (e.g., Athens, Rome, Lisbon) and Central and Eastern European Cities (e.g., Bucharest, Sofia, Zagreb) lag in GDP and SDG scores. This indicates a sustainability gap, likely due to economic constraints or slower policy implementation.

The sampling frame are specifically European cities which are signatories of the Covenant of Mayors network. The question arises how representative are the 45 cities of the total EU city portfolio? The sample of cities should represent five categories of cities by Covenant of Mayor standards. This includes:

- Signatories with population < 10,000
- Signatories with population 10,000 - 50,000
- Signatories with population 50,000 - 250,000
- Signatories with population 250,000-500,000
- Signatories with population > 500,000

**Figure 11** presents the population distribution of the EU SDG Index 2019 sample. Notably, 65% of the 45 cities included in the index fall into the largest CoM category, with populations exceeding 500,000. This skews the sample toward large metropolitan areas and leaves smaller cities underrepresented.

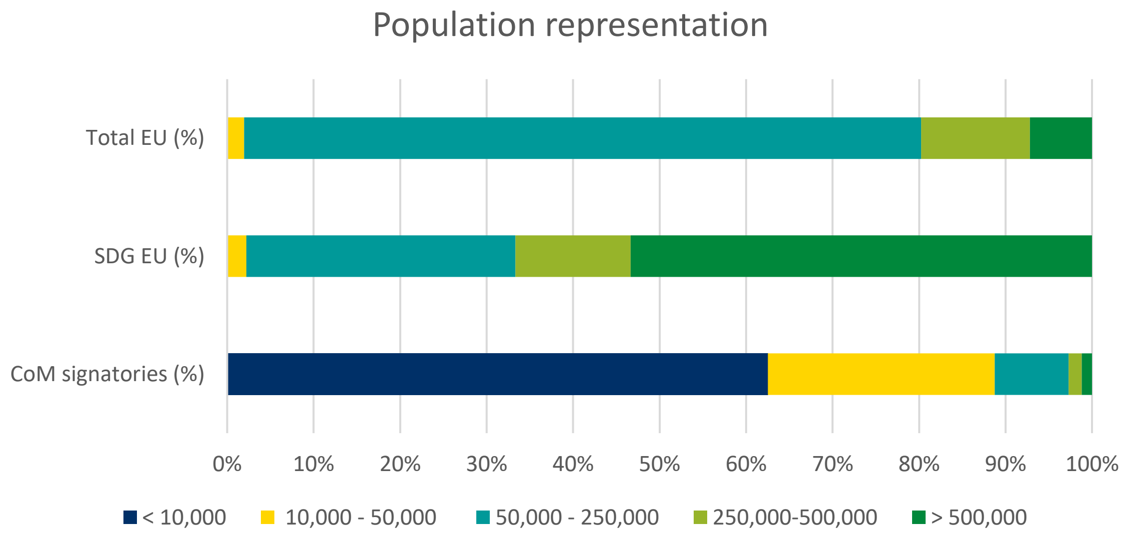



**Figure 11**: Sample frame population distribution.
*Source: Author*

To address this gap and ensure broader representativeness in subsequent testing (Sections 4.1–4.3), three cities were selected based on their varied population sizes: Litoměřice, Czechia (24,000); Maribor, Slovenia (112,395); and Zagreb, Croatia (772,122). While not proportional to CoM population distribution, these cities provide meaningful coverage of different urban typologies. The decision to avoid strict proportional sampling is justified by the heterogeneity in EU urban structures and the CoM registry itself, where many signatories are small administrative units, while a majority of EU urban populations (80%) live in cities between 50,000 and 250,000 inhabitants.

### 3.4.2 Mapping SDGs to SYNERGISE+ Dimensions

The Sustainable Development Goals (SDGs) are not isolated objectives; rather, they are characterised by intricate interconnections that involve both synergies and trade-offs (ICSU, 2017). For the purpose of our SDG analysis, however, trade-offs are disregarded. Each SDG is instead appropriated into a corresponding SYNERGISE+ dimension. This approach allows us to investigate which systemic dimensions contribute most significantly to a city's or nation's success in achieving the SDGs.

The 17 SDGs, each scored between 0 and 100, provide a global benchmark for sustainable progress. Although the original SDG methodology applies weighted averages, the difference from non-weighted scores is negligible (<0.5%). Therefore, unweighted averages were used when assigning SDG scores to the five SYNERGISE+ dimensions, enhancing comparability and clarity.

The following table (**Table 21**) provides a summary of matching SDG with SYNERGISE+ dimension, while a full list of SDGs and a visual representation is given in Appendix D.

**Table 21:** Mapping of Sustainable Development Goals (SDGs) to SYNERGISE+ dimensions, showing how SDGs align with the five core dimensions and key criteria.

| No. | SYNERGISE+ Dimension | Relevant SDGs (new total score is an average of all SDGs score belonging in that dimension) |
|---|---|---|
| 1 | ENVIRONMENTAL IMPACT | SDG7 Affordable and Clean Energy, SDG15 Life on Land, SDG13 Climate Action |
| 2 | ECONOMIC VIABILITY | SDG8 Decent Work and Economic Growth |
| 3 | SOCIAL EQUITY | SDG1 No Poverty, SDG2 Zero Hunger, SDG5 Gender Equality, SDG10 Reduced Inequalities, SDG3 Good Health and Well-Being, SDG4 Quality Education, SDG6 Clean Water and Sanitation |

| | | |
|---|---|---|
| 4 | TECHNICAL FEASIBIL. & COMPETITIVENESS | SDG9 Industry, Innovation, and Infrastructure<br>SDG11 Sustainable Cities and Communities |
| 5 | INSTITUTIONAL FRAMEWORK | SDG12 Responsible Consumption and Production;<br>SDG16 Peace, Justice, and Strong Institutions |

*Source: Author*

Although several SDGs overlap dimensions due to their cross-cutting nature, reflecting their broader impact on sustainability, here each SDG was fitted to only one dimension. Some considerations in this assignment of SDGs to the SYNERGISE+ dimensions were:

- Clean water and sanitation (SDG6) can fit the environmental dimension, however, all cities perform extremely well on this criterion, with an average score of 96 (97% of the cities having a result over 90). Thus, it is an outlier which, if included in the environmental category would extremely skew the results and give a wrong impression of good performance. Obtaining indicators for water quality on local level is rather difficult; thus, the SDG 9 city indicator measured merely the percentages of: a) regional average of wastewater treated and, b) population connected to sewerage treatment. Thus, the basic water sanitation is not a reliable sign of sustainable progress but bare minimum of quality urban living. Therefore, this category is included under the social dimension – criteria quality of life.
- Economic viability is represented solely by decent work and economic growth. Responsible consumption and production (SDG12), with a low average score of 59, when incorporated into the economic dimension, slightly lowers the average. Nevertheless, economic viability remains the best-performing dimension for cities. SDG12 has been placed into the institutional framework, with the aim of ensuring sustainable consumption and production patterns through enhanced policies and legal frameworks.
- Sustainable cities and communities (SDG11) can be incorporated into both social equity and technical feasibility & competitiveness without altering the results of either dimension. However, it has been retained in the technical feasibility & competitiveness dimension, as sustainable communities are primarily indicators of innovation and serve as examples of good practice for broader adoption by other communities.

### 3.4.3 Comparative SDG Performance at City and Country Level

The SDG EU Cities 2019 and SDG World Index 2024 databases were analysed in relation to five distinct development scenarios, each representing different approaches to sustainability. These scenarios are as follows: 1) **Balanced scenario**, where a city places equal importance on all dimensions and criteria, with the scores across dimensions differing by less than 10%; 2) **Technocratic scenario**, where the technical dimension is prioritized, with its score being the highest, exceeding the lowest scored dimensions by 10% or more; 3) **Conventional scenario**, where economic considerations dominate, often at the expense of environmental and social dimensions. Specifically, the social dimension or any environmental SDG category (see Figure 11 for criteria of the environmental impact dimension) ranks as the lowest or second-lowest score; 4) **Sustainable scenario** emphasizes environmental goals and social well-being, where these dimensions score at least 10% higher than the lowest scored dimension, indicating a commitment to sustainability regardless of associated costs or required technological and legal changes.

The study hypothesizes that the Conventional scenario is the most observed, while the Sustainable is the least prevalent. It is important to note that these scenarios are mutually exclusive but not collectively exhaustive. The focus of the study is on examining these five specific approaches to understand the general strategies cities and countries adopt on their journey toward sustainable development, as well as the frequency and relevance of each scenario (**Table 25**). Both databases were also tested for correlation between the score, and each of the five dimensions (dependent, discrete variables) and city/nation population, region, country income and GDP (independent variables) using Pearson's test. Additionally, Spearman correlation was used for determining correlation between city population and GDP rank, and Kruskal-Wallis nonparametric test was used for determining correlation between the city score and the nominal category of region (for cities). When correlations ranged from 0.3 to 0.7, a multivariate linear regression was performed (through RStudio, version: 2024.04.2) to assess the interconnection between the dependent variable – EU Cities SDG 2019 score and the explanatory variables: city GDP and the SDG World Index 2024. Multicollinearity, heteroskedasticity and normality of residuals were checked respectively with the Belsley-Kuh-Welsch technique, the Breusch-Pagan test and the Shapiro-Wilk test. A p-value $< 0.05$ was considered statistically significant.

# 4. Results and Analysis

### 4.1 SYNERGISE+ Model Output Overview

The model generates a prioritized list of actions, offering two distinct outputs: one based solely on the score without considering the cost, and another that incorporates implementation costs, highlighting actions that align with expressed preferences and fall below the average cost. Additionally, the model provides an automatic, comprehensive scorecard (**Figure 12**) that explains the results, offering the following key insights:

- Action Assessment: Presents the number and percentage of actions aligning with the city's expressed values, alongside an evaluation of efficiency. This includes identifying actions below the average implementation cost, offering insight into potential areas for cost-efficiency improvements.
- Overall Performance: Highlights the city's average score across all criteria, emphasizing the strongest and weakest dimensions to pinpoint areas of success and those requiring improvement.
- Value Alignment: Identifies the highest- and lowest-valued criteria, analysing whether these align with the city's actions. This ensures that the city's sustainability efforts reflect its stated priorities.
- Targeted Climate Risks: Evaluates whether the city's actions are targeted towards its most significant climate vulnerabilities, issuing warnings when high-risk hazards are not adequately addressed. This ensures that cities remain proactive in mitigating the most pressing climate threats, further strengthening the effectiveness of their sustainability strategies.
- Synergies: Identifies actions with synergy potential and estimates potential savings from leveraging those identified synergies if the actions are implemented simultaneously.
- Areas for Improvement: highlights areas for improvement, such as actions with negative environmental impacts, particularly within EU Taxonomy subcategories.

This detailed analysis equips decision-makers with actionable insights, enabling them to optimize their sustainability strategies effectively.

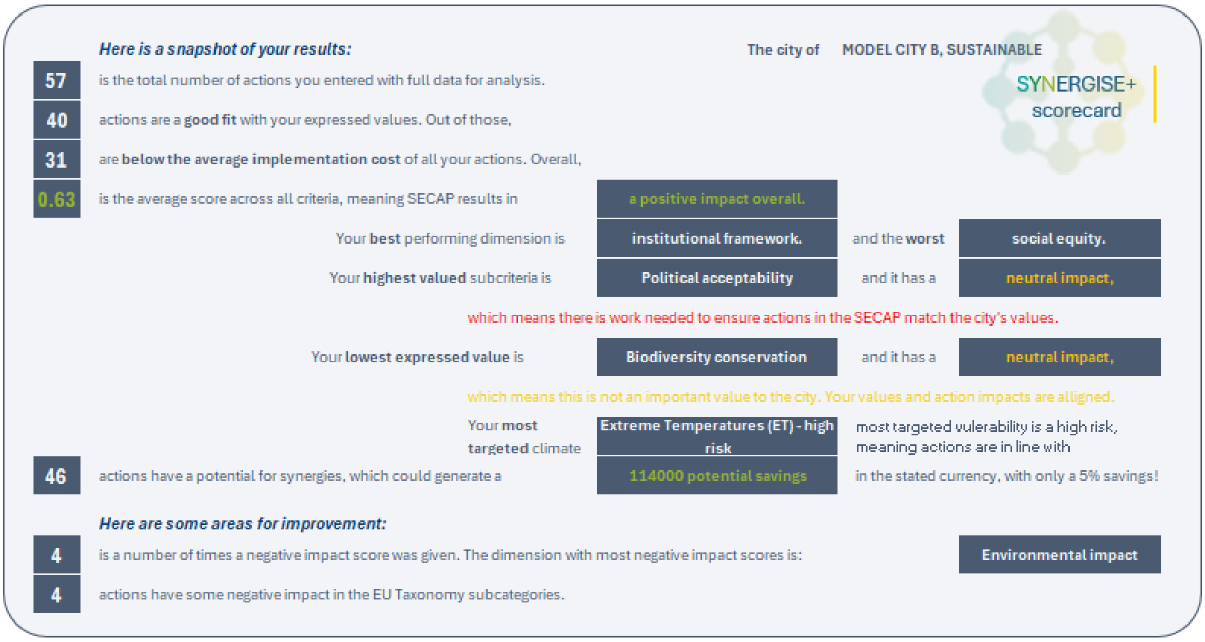



**Figure 12**: Example of a city Results scorecard generated by the SYNERGISE+ tool.
*Source: Author*

### 4.2 Robustness of the Weighting Approach

The objective was to assess the reliability of the SYNERGISE+ pairwise comparison weight elicitation approach by comparing it with an established weight elicitation and ranking method (PAPRIKA) and determine whether SYNERGISE+ produces comparable weight distributions to an advanced conjoint analysis tool. Two approaches were used:

A controlled experiment comparing theoretical weight sets assigned through SYNERGISE+ and PAPRIKA software (Hansen and Ombler, 2008b). Four value scenarios were used in both frameworks (**Table 22**), with the fifth, technocratic scenario introduced only on the EU SDG dataset. The results show a strong correlation between weight distributions derived from pairwise comparisons in SYNERGISE+ and PAPRIKA, with an average correlation of 95%. This demonstrates that SYNERGISE+ successfully replicates PAPRIKA outcomes through a simpler and more user-friendly approach, requiring only 19 pairwise comparisons instead of exhaustive pairings. Additionally, the model remains robust and stable across scenarios, validating its ability to accurately capture decision-makers' preferences without the need for advanced software.

Application of four predefined value scenarios (Balanced, Conventional, Sustainable, Extreme) in both tools to assess consistency in weight outputs by using three existing three SECAPs, and two model test cities, to simulate the effect of weights on actual case studies in four predetermined scenarios (**Table 16**).

### 4.2.1 Comparing SYNERGISE+ and PAPRIKA Weight Elicitation Techniques

The results show a strong correlation between weight distributions derived from pairwise comparisons in SYNERGISE+ and PAPRIKA, with an average correlation of 95%. This demonstrates that SYNERGISE+ successfully replicates PAPRIKA outcomes through a simpler and more user-friendly approach, requiring only 19 pairwise comparisons instead of exhaustive pairings. Additionally, the model remains robust and stable across scenarios, validating its ability to accurately capture decision-makers' preferences without the need for advanced software.

Both methods apply conjoint analysis via pairwise comparisons to elicit weights for decision criteria, but they differ in complexity and structure. PAPRIKA uses software to compare nearly all possible combinations of choices, while SYNERGISE+ reduces the burden by limiting comparisons to a minimum, maintaining usability without compromising accuracy. Furthermore, SYNERGISE+ employs a two-level structure, eliciting preferences for both dimensions and sub-criteria, whereas PAPRIKA operates on a single, dispersed level of criteria.

**Table 22:** Comparison of value (weight) elicitation simulation through PAPRIKA and SYNERGISE+ methodologies.

| **Name** | **Explanation** | **Correlation** | **Euclidean distance** |
|---|---|---|---|
| Balanced scenario | There is no preference, meaning all criteria are valued equally. | 0%[1] | 0.06 |
| Conventional scenario | Political acceptability and ROI are given maximum weight, followed by balanced social equity, institutional framework and technological dimension, overlooking the biodiversity and risk and vulnerability impact. | 93% | 0.06 |
| Sustainable scenario | Environmental goals and social wellbeing are paramount, regardless of the cost or necessary technology and legal changes to achieve them. | 97% | 0.04 |
| Extreme scenario | Maximum possible differences in weights that the model can create. | 96% | 0.05 |

**(1)** The final balanced scenario is the only one that bypasses dimension-level weighting and directly assigns equal importance to all second-level criteria, with each receiving 8.3% (100/12). This ensures a balanced distribution. While the final weights match those in PAPRIKA, this alignment occurs by deliberate design rather than through an inherent calculation process.

*Source: Author*

It is evident that, given the relatively simple structure of SYNERGISE+ with only 12 second-level criteria, the use of more sophisticated decision-making software did not lead to significantly different results. On average, both tools produced highly similar weight distributions (95% similarity) and resulted in the same prioritization when applied to the same set of actions and values.

The only notable variance emerges in the case of the original balanced scenario, due to the hierarchical weighting structure in SYNERGISE+, where weights are first assigned to dimensions before being distributed among criteria. Dimensions with three criteria receive lower individual weights (6.7%) than those with two (10%), as weights are normalized within each dimension. In contrast, PAPRIKA applies a single-level pairwise comparison, ensuring equal weighting across all second-level criteria, regardless of their grouping.

To address this imbalance, SYNERGISE+ methodology disregards the dimension, or first-level criteria only in the balanced scenario, so that all second-level criteria are assigned equal weight. This approach ensures that when a decision-maker is entirely neutral or undecided, each criterion contributes equally to the assessment, preventing undue influence from dimensions with fewer criteria. By eliminating the hierarchical weighting effect, this method maintains analytical fairness and prevents arbitrary dominance of certain dimensions. As a result, the final Balanced Scenario in SYNERGISE+ eliminates dimension-level weighting, directly assigning an equal 8.3% weight to each of the 12 criteria. This adjustment ensures a truly balanced evaluation, resolving discrepancies caused by hierarchical distribution, but it results with no correlation with PAPRIKA.

### 4.2.2 Scenario Testing on Three Existing and Two Model SECAPs

Once the process of eliciting values and translating them into criteria weights has been established, it is crucial to assess the impact these weights have on the final ranking of actions. To explore this, a simulation exercise was conducted using four of the five scenarios – Balanced, Conventional, Sustainable and Extreme – on actual SECAPs from the cities of Zagreb (Croatia) (EIHP, 2017), Maribor (Slovenia) (ENERGAP, 2021), and Litoměřice (Czechia) (ENVIROS, PORSENNA and HO Base, 2018), as well as the two model cities. The analysis utilised the actual SECAP actions and investment costs where available. The impact of each action was estimated using expert judgment, and the assumptions made for valuing actions across all three cities were consistent, employing the same logic and methodology. For Litoměřice and Maribor, these estimates were validated by the SECAP creators, and for Zagreb the estimates were based on author's assumptions.

A sensitivity analysis of potential weight combinations was then conducted using three of the four predefined value scenarios—Balanced, Conventional, Sustainable and Extreme (**Table 16**)—across the five cities: three real case SECAP studies and two model cities. Since the three real-case cities have successfully implemented SECAPs and follow similar sustainability and institutional frameworks, as well as share a four-season climate, a similar number and type of SECAP actions, and comparable climate hazards, two additional model cities were introduced to test the model's ability to distinguish between different sustainability approaches: (a) Model City A – Conventional, which aligns more with conventional SECAP values, prioritising institutional and economic factors over sustainability, and; (b) Model City B – Sustainable, which strongly favours sustainable goals, even at the expense of institutional frameworks or economic feasibility.

The objective was to test whether the SYNERGISE+ model can accurately reflect the strategic priorities of real SECAPs when applied to existing city plans and evaluate the stability and sensitivity of rankings across different value scenarios. The results are summarized in Table 23, and a full analysis is available in Appendix C.

**Table 23:** Sensitivity analysis of the three SYNERGISE+ scenarios.

| **Scenario sensitivity analysis** | **Average results across all scenarios** |
|---|---|
| 'Rank distribution: % of actions changing rank | 79% |
| Average Rank consistency: % of actions from top 10 that stayed in top 10 | 76% |
| Average Rank consistency: % of actions from top 10 that stayed in top 20 | 82% |
| Average number of rank change across all scenarios | 6 |

*Source: Author*

The findings indicate that, on average, 79% of actions experienced rank changes across different scenarios. However, when examining the highest-ranking actions, the analysis revealed that 76% of actions remained within the top 10, while 82% retained their position within the top 20. The average rank shift (either promotion or demotion) in the tested scenario with five different cities was six places, reinforcing the model's robustness in maintaining consistency while allowing for scenario-based adjustments.

This signifies that the model effectively captures implicit priorities within SECAPs, confirming that cities tend to allocate resources based on their value focus areas.

Scenario-based testing demonstrates model robustness, proving that it remains reliable while adapting to different city decision-making frameworks.

### 4.3. Impact Assessment on the Three SECAP Case Studies

Once the model identifies the best-fitting scenario—that is, the predetermined value scenario most closely aligned with the actual impact scores assigned by the decision-maker—it provides an impact assessment of the SECAP under the given assumptions. A summary of three city SECAPs, including two model cities, is presented in **Table 24.**

The objective was to measure whether SECAP actions align with sustainability goals or economic priorities, and to evaluate the cost-effectiveness of synergy-based planning within SECAPs. The results demonstrate that SYNERGISE+ effectively distinguishes between different sustainability priorities and captures variations in SECAP planning.

For the purpose of this simulation, it is assumed that cities lack the capacity to implement all actions simultaneously and will instead prioritize the highest-ranked actions first. This approach allows for an assessment of differences in impact when certain actions are implemented together. Specifically, the model identifies the best-fit scenario for each city based on its SECAP actions; In Maribor (53%) and Litoměřice (91%), most SECAP actions reflect the priorities of the Conventional scenario, where economic and institutional feasibility take precedence over environmental and social factors. In contrast, Zagreb (56%) follows a Balanced approach, distributing importance more evenly across all sustainability dimensions.

The average criteria scores across all cities range from 0.62 to 0.68 (on a scale of 1), indicating a generally positive impact. The Institutional framework is the strongest dimension across most cities, whereas Technical feasibility, Economic viability, and Environmental impact rank lowest. Model results highlight the strengths and gaps in SECAP implementation, emphasising the need for better integration of sustainability actions and maximization of synergies to improve cost-effectiveness and climate resilience.

Additionally, the analysis reveals that each city exhibits some negative impacts, which the model detects and flags, particularly when these impacts fall within areas covered by the EU taxonomy. This functionality enables cities to quickly assess the alignment of their plans with EU sustainability regulations and implement necessary adjustments to enhance compliance.

Finally, to estimate the potential savings from synergistic planning, all actions with identifiable synergies were selected and their total implementation cost summed for each city. Although this research presents methodology for calculating synergy-related savings in Section 3.3.3, it was not applied due to data limitations. However, a conservative estimate can be made by applying a savings rate of 5% to aggregated implementation cost of all synergistic actions, representing the assumed efficiency gain from coordinating the implementation of these actions. This approach yielded estimated savings of approximately EUR 989,567 for Zagreb, EUR 188,750 for Maribor (noting that half actions lacked cost data), and EUR 11.7 million for Litoměřice.

Although the 5% figure is an approximation, it provides a useful ballpark estimate to illustrate that even minimal coordination efforts could result in significant financial benefits, thereby justifying the added effort required for integrated planning.

**Table 24:** Impact assessment summary.

| **Tested cities:** | **Maribor, Slovenia (real SECAP)** | **Zagreb, Croatia (real SECAP)** | **Litoměřice, Czechia (real SECAP)** | **Model city A - Conventional** | **Model city B - Sustainable** |
|---|---|---|---|---|---|
| Population (from SECAP)**:** | 112.395 (from SECAP) | 772 122[2] | 24 000 (from SECAP) | | |
| Number of SECAP actions: | 57 | 57 | 48 | 54 | 54 |
| Dominant value-preference scenario: | 53% of actions fit the Conventional scenario | 56% of actions fit the Balanced scenario | 91% of actions fit the Conventional scenario | 81% of actions fit the Conventional scenario | 98% of actions fit the Sustainable scenario |
| Scenario distribution of actions (Balanced/ Conventional/Sustainable) | 34/**38**/28 | **32**/30/30 | 40/**44**/40 | 30/**44**/24 | 51/40/**53** |
| Average action score (0–1 Scale) | 0.62/1 | 0.62/1 | 0.66/1 | 0.63/1 | 0.68/1 |
| Overall SECAP outcome: | Positive impact overall | Positive impact overall | Positive impact overall | Neutral impact overall | Positive impact overall |
| Highest-scoring dimension: | Institutional framework | Institutional framework | Institutional framework | Institutional framework | Social equity |
| Lowest-scoring dimension: | Technical feasibility & competitiveness | Economic viability | Technical feasibility & competitiveness | Environmental impact | Institutional framework |

| | | | | | |
|---|---|---|---|---|---|
| Predominant climate hazard addressed: | Extreme temperatures - high risk | Extreme temperatures - high risk | Extreme temperatures - high risk | Neutral impact overall | Positive impact overall |
| % of actions with synergies potential: | 81% | 84% | 81% | | |
| Potential savings from synergies (5% savings assumption) | EUR 188,750[1] | EUR 989,567 | EUR 11,7 mil | | |
| Frequency of actions with negative impact scores: | 2 | 1 | 1 | / | / |
| Number of actions with negative EU taxonomy alignment: | 1 | 1 | 0 | / | / |
| Dimension most associated with negative impacts: | Environmental impact | Economic viability | Environmental impact | / | / |

(1) 46% of SECAP actions for Maribor did not have the implementation cost provided

(2) Statistics from official websites of the City of Zagreb (Zagreb, 2025)

*Source: Author*

### 4.4 Understanding SDGs Progress Through the SYNERGISE+ Lens

The following section presents an analysis of the performance of the 2019 European Cities SDG Index, which includes 45 cities, and the 2024 World SDG Index, covering 167 countries with complete data (Figure 10). Resulting are performance trends for EU cities and world data, shown on **Figure 13** and **Figure 14**.

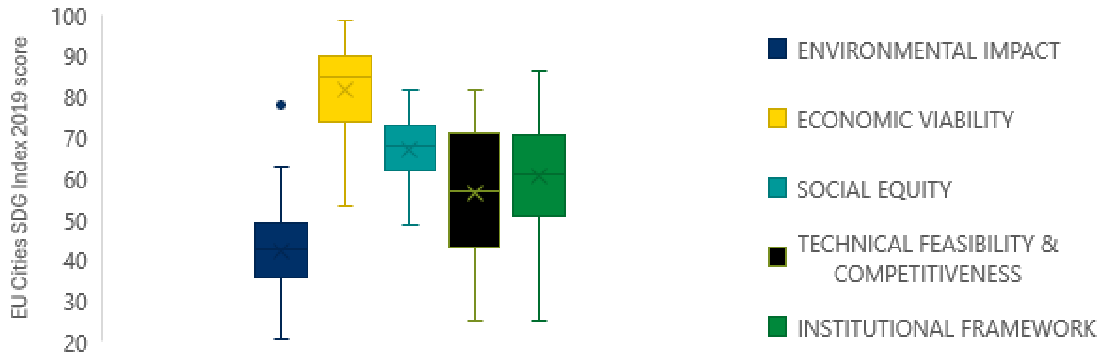



**Figure 13:** Performance trends by dimension for Cities SDG 2019 data.
*Source: Author*

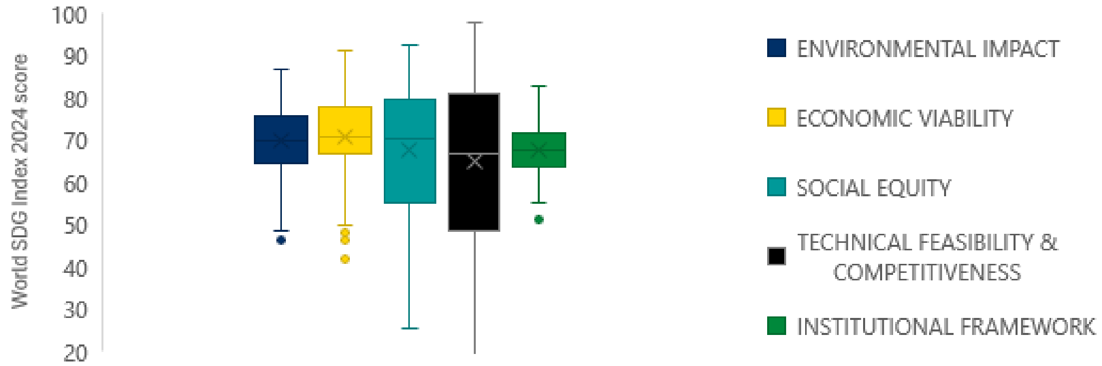



**Figure 14**: Performance trends by dimension for UN World SDG Index 2024 data.
*Source: Author*

Countries generally perform uniformly in environmental, economic, and institutional dimensions, with social and technical aspects being the differentiators. On the contrary, cities are excelling economically at the expense of the environmental impacts. The tests (**Table 25**) reveal a moderate positive correlation (0.62) between city and national SDG scores. A strong positive correlation exists between region and scores for EU cities (0.84), and between country income status and national scores for world countries (0.81). This indicates that for EU cities, region alone can predict results, with Northern Europe leading and Southern Europe lagging. On a national level, higher income correlates with better performance in social equity and technical dimensions, followed by economic viability. All countries, irrespective of income, perform similarly in environmental and institutional dimensions.

The **City SDG Score** has a highly significant impact on the social, and technical, and significant impact on the economic and institutional dimension, and does not significantly impact the environmental dimension (**p > 0.05**). The correlation between population and GDP is generally negligible. However, SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure) show moderate positive correlations with city GDP. These two SDGs also exhibit the highest correlations with region, GDP, and national SDG scores, highlighting their role in driving sustainable development.

**Table 25:** Tests performed on city data, for total score and individual dimensions.

| No. | Independent variables | Analysis – compared to city SDG score – discrete, dependent | Total score | Environmental | Economic | Social | Technical | Institutional |
|---|---|---|---|---|---|---|---|---|
| 1 | City GDP – continuous | Pearson correlation | 0.26 | 0.02 | 0.35 | 0.22 | 0.43 | 0.01 |
| 2 | City GDP rank – ordinal | Spearman correlation (rank with SDG rank) | 0.39 | -0.06 | 0.91 | 0.61 | 0.77 | 0.56 |
| 3 | Country SDG 2024 score - discrete | Pearson correlation | 0.62 | 0.12 | 0.32 | 0.54 | 0.48 | 0.37 |
| | | Multivariate regression **Pillai's trace = 0.340, F (1,43)=** | | 0.77 | 4.81 | 17.08 | **12.74** | **6.94** |
| 4 | Country SDG 2024 rank – ordinal | Spearman correlation (rank with SDG rank) | 0.44 | 0.01 | 0.18 | 0.35 | 0.32 | 0.25 |
| 5 | City region – nominal, 4 categories | Kruskal-Wallis chi-squared for total SDG score only = | 42.646, df = 40, p-value = 0.358 | | | | | |

*Source: Author*

An assessment determined which scenario each city and country align with, revealing development priorities (**Table 26**). Notably, 87% (39 out of 45) of cities and 20% (34 out of 167) countries fit the conventional scenario, excelling economically but underperforming socially and/or environmentally. The lowest-performing dimension is environmental impact for cities and technical for countries, with 67% of cities struggling with either emission reduction or biodiversity conservation). Social, technical, and institutional dimensions fall between these extremes, with technical feasibility showing the greatest range towards lower scores.

**Table 26**: Results interpretation for both city and country datasets.

| No. | Results | EU Cities SDG Index 2019 Score | World SDG Index 2024 Score |
|---|---|---|---|
| 1 | Scenario frequency in order of prevalence | 87% conventional, 0 balanced, sustainable or technocratic | 26% technocratic, 23% sustainable, 20% conventional, 10% balanced[1] |
| 2 | Cities/countries that do not align with scenarios | 7% social dimension the highest, environmental the lowest | 11% institutional highest, 8% social highest, 9% technical lowest |
| 3 | Best performing dimension | 89% economic dimension | 28% both environmental and technical dimension |
| 4 | Worst performing dimension | 67% environmental dimension, emission reduction is the worst individual criteria on average | 43% technical dimension, although emission reduction is the worst individual criteria on average |
| 5 | % of cities/countries with score > 70 per dimensions | ENV 2%, ECON 80%, SOC 42%, TECH 27%, INST 29% | ENV 47%, ECON 53%, SOC 53%, TECH 39%, INST 32% |
| 6 | Dimensions slope from best to worst score | All except environmental (horizontal) exhibit mild downward slope | Technical and social have a high steep downward slope |
| 7 | Average distance from best to worst dimension | 0.44 (44%)[1] | 0.24 (24%), however[1] |

**(1)** 75% of countries (and only 13% of cities) have less than 30% difference among worst and best dimensions, meaning they remain closely aligned with the balanced scenario

*Source: Author*

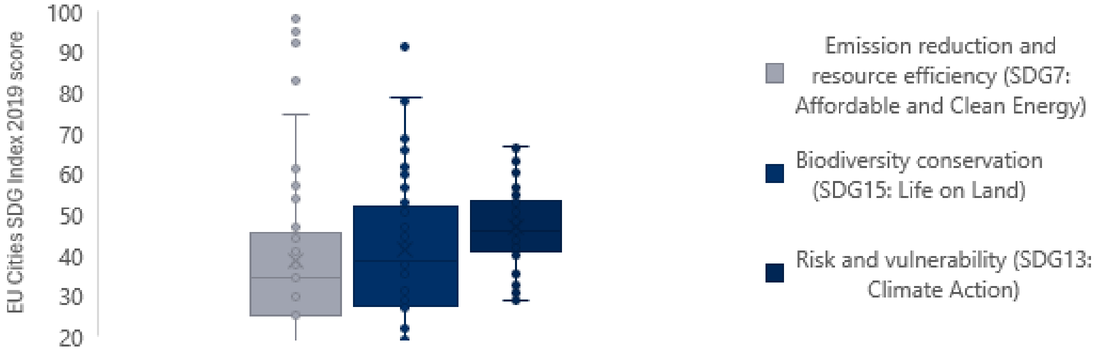
### 4.4.1 Performance Trends at the National Level

For the World SDG 2024 Index, scores are balanced across all dimensions, with high and low averages only 30% apart for 75% of the cities, indicating similar attention to all areas. Despite technical dimensions performing poorly on average (worst dimension for 43% of countries), 39% of countries excel in this area (score >= 70). The data slope for cities shows all except environmental dimension have a mild downward trend, while technical and social dimensions significantly improve with higher scores.

### 4.4.2 Performance Patterns Across European Cities

When examining cities that are performing well (score >= 0.7), it becomes clear that there is a tremendous opportunity to further elevate environmental goals, as currently only 2% of cities achieve a score of 0.7 or higher in this area. A deeper analysis reveals that as cities improve overall, their success is consistently distributed across all dimensions, except environmental impact which shows low performance unrelated to overall rank, offering significant potential for enhancement. Environmental impact shows varied performance unrelated to overall rank.

The stark underperformance in the environmental impact dimension across cities is illustrated in **Figure 15**




, highlighting the superior performance of SDG 13 (Climate Action), which demonstrates the lowest variance. This figure is crucial in understanding the broader implications of environmental underperformance, as the exclusion of climate action would further deteriorate the results. Additionally, the discussion later shows how SDG 13's performance may be inflated due to its reliance on softer indicators.

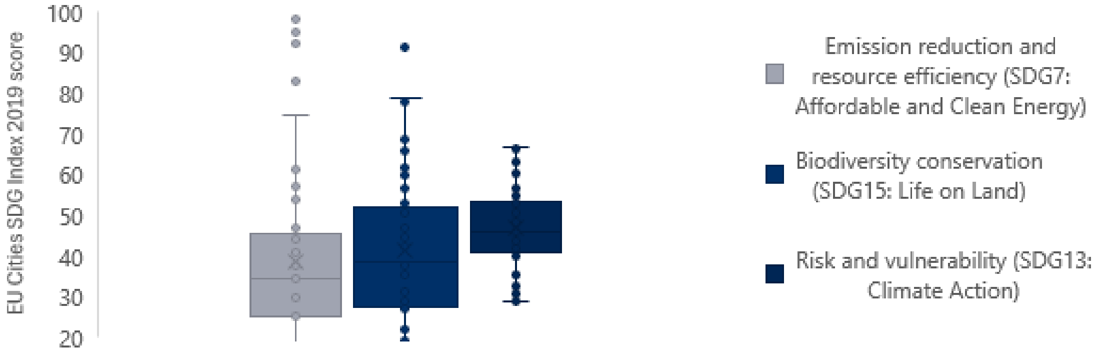



**Figure 15**: Graphical representation of the SDG EU Cities data for the environmental impact dimension, including separate mapping of the three associated SDGs. Axis labels represent SDG total scores, and the legend highlights criteria groupings.
*Source: Author*

Cities were grouped into the following categories based on performance patterns:

- Conventional Cities (62% of cities): These cities exhibit strong performance in economic viability while scoring lowest in environmental impact. This cluster predominantly includes Central and Eastern European cities such as Warsaw, Budapest, and Zagreb, indicating a persistent focus on economic growth.
- Balanced Cities (18% of cities): Cities like Rotterdam and Lyon show relatively uniform performance across dimensions without pronounced strengths or weaknesses. This typology suggests diversified approaches to sustainability, balancing growth with environmental stewardship.
- Sustainable Cities (7% of cities): Few cities, such as Stockholm and Helsinki, demonstrate higher environmental scores, prioritizing sustainability measures over short-term economic benefits.
- Technocratic Cities (13% of cities): Cities like Munich and Copenhagen emphasize technical feasibility, particularly through investments in infrastructure and innovation.

A regional breakdown reveals distinct regional patterns: Western and Northern European cities generally align with balanced or technocratic profiles, reflecting stronger environmental and technical investments. Conversely, Central and Eastern European cities more often exhibit conventional characteristics, indicating the predominance of economic goals.

#### 4.4.3 Socioeconomic Drivers of Sustainability Outcomes

The most surprising finding was that the strongest predictor of SDG success was city GDP and country income, underscoring the persistent dominance of economic factors in shaping sustainability outcomes. This highlights the challenge of aligning economic growth with ambitious environmental and social objectives, emphasizing the need for more integrative policy frameworks.

**Figure 16** illustrates the relationship between income levels and performance across the five SYNERGISE+ dimensions, using World SDG Index 2024 scores. The graph highlights that high-income countries excel in technical feasibility and social equity, while income disparities are less pronounced in environmental impact and institutional framework.

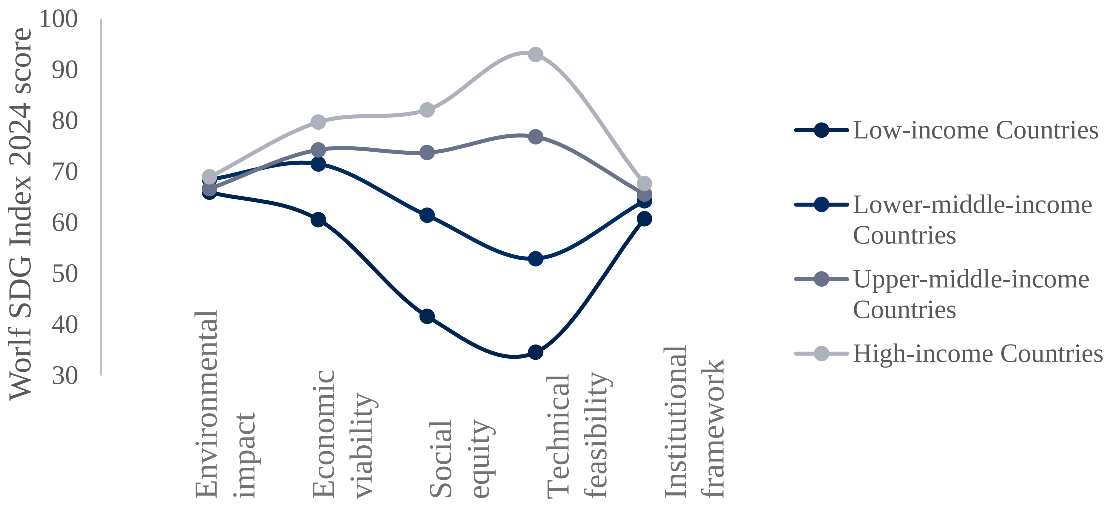



**Figure 16:** World SDG Index 2024 by income group (low-, lower-middle-, upper-middle-, and high-income) depicted through SYNERGISE+ dimensions. Distinct lines for each income group.
*Source: Author*

In summary, Figures 12 and 13 emphasize the need for a recalibration of priorities, as current economic gains often overshadow essential environmental progress. These figures underscore the significant influence of wealth on SDG performance, particularly in the technical and social dimensions. They emphasize the need for more ambitious environmental efforts, especially from higher-performing cities and countries with the capacity and resources to advance environmental goals more effectively.

## 4.5 Interpreting Key Findings

### 4.5.1 Misaligned Priorities in Urban Climate Planning

The applications indicate that, while institutional and economic feasibility remain dominant, environmental and social considerations often receive lower weightings, highlighting a disconnect between high-level climate commitments and actual mitigation and adaptation priorities.

Simulation of different value-based scenarios (Balanced, Conventional, Sustainable, Technocratic) shows that cities' prioritization structures shift based on explicit and implicit decision-making values. This raises questions about whether SECAPs reflect true sustainability objectives or are shaped by financial and political constraints. Additionally, cities are not fully leveraging synergies between mitigation and adaptation actions, leading to inefficiencies in implementation and missed opportunities to enhance climate resilience and resource optimization.

The analysis suggests that a more integrated approach could improve cost efficiency and sustainability outcomes, though the extent depends on local contexts, financial mechanisms, and governance structures. While SYNERGISE+ estimates potential savings from synergy-driven actions, these figures should be seen as illustrative rather than fixed financial projections. For example, in Litoměřice, over 80% of actions could be linked through synergies, indicating opportunities for cost-effective implementation. However, actual benefits rely on local execution, funding, and institutional coordination.

To enhance SECAP effectiveness, actions should be assessed holistically rather than in isolation. Decision-makers must actively evaluate co-benefits, adopt synergy-driven prioritization frameworks, and allocate resources to maximize collective impact. Beyond technical adjustments, municipalities must improve institutional coordination and combine budget—areas often overlooked in sustainability planning. Further research is needed to refine methodologies for quantifying and integrating synergies.

Weight elicitation analysis reinforces these findings. Given the option to adjust prioritization criteria, decision-makers consistently preferred financial feasibility and political alignment over environmental impact. Maribor and Litoměřice aligned best with the Conventional Scenario, emphasising return on investment and institutional factors, while Zagreb's SECAP reflected a more Balanced approach. Notably, in the Sustainable Scenario, where environmental and social factors take precedence, action rankings shifted significantly—demonstrating both the flexibility of SECAPs and their susceptibility to economic and political considerations. This underscores a critical limitation: while SECAPs are framed as sustainability-driven, their implementation is largely constrained by financial and political feasibility. As a result, sustainability objectives risk being deprioritized in favour of lower-barrier actions, reinforcing the need for structured decision-support tools like SYNERGISE+ to align policy ambitions with actionable strategies.

### 4.5.2 Urban Sustainability: Still an Economic Game, the case of SDGs

> The analyses validates the prevalence of the conventional scenario, as evidenced by the 2019 SDG data for 45 European cities: 89% performed best in the economic dimension, while 67% scored lowest in the environmental dimension (**Table 26**). This stark contrast reinforces the dominance of economic priorities over environmental efforts.

This pattern emphasizes that economic objectives remain dominant, with environmental goals receiving comparatively less focus. However, the 2024 World SDG Index suggests a more balanced global approach, driven largely by income disparities, where technical performance emerges as a key differentiator: 28% of countries excel and 43% underperform in this dimension. Additionally, high-income countries consistently top the SDG rankings, while the first low-income country appears only at 48th place, highlighting the impact of economic status on overall performance.

Despite this, only 23% of countries—and no cities—align with the sustainable scenario, underscoring a global shortfall in environmental progress. Cities that prioritize environmental sustainability remain a minority, with the prevalence of conventional cities highlighting the ongoing challenge of shifting urban agendas toward more environmentally balanced models. This gap can be partially attributed to historical biases favouring economic growth, which has been the primary focus for centuries. However, recent trends show that economic advancements continue to outpace environmental progress, indicating a persistent imbalance in sustainability efforts.

Moreover, the technical dimension, comprised of SDG 9 (industry, innovation and infrastructure) and SDG 11 (sustainable cities and societies) for the world countries, and technical and social dimension for the EU cities, consistently emerge as a key performance differentiator, a pattern that aligns with findings from the broader SDG data. This relationship underscores the need for targeted investments in green infrastructure to bridge the gap and promote more sustainable development practices. Notably, for world countries SDG 9 (industry, innovation, and infrastructure) is a decisive factor, displaying the highest variance between top and bottom performers. The disparity is partly due to global trends such as declining manufacturing growth, which advanced economies manage more effectively than lower-income nations. This pattern is further supported by decomposition analyses of $CO_2$ emissions, such as in Greece from 1996 to 2020, where technological advancements and improved efficiency were found to be major contributors to lowered emissions, and they followed economic growth (Tsepi, Sebos and Kyriakopoulos, 2024)These findings reinforce the idea that enhancing industrial innovation and technological capacity is essential for sustainable economic development and environmental resilience, particularly for nations seeking to close the sustainability performance gap.

Surprisingly, environmental impact showed minimal variation across EU cities, despite significantly greater investments in mitigation than adaptation (Dizdaroglu, 2017). This discrepancy may stem from the indicators used for tracking city-level climate action. SDG 13 (Climate Action) consists of soft targets such as education and policy integration, contrasting with SDG 7 (Clean Energy) and SDG 15 (Life on Land), which are measured through concrete, resource-intensive targets (e.g., energy shares, GDP, financial flows). Consequently, the relatively higher scores for SDG 13 may reflect less ambitious targets rather than substantive progress.

The relevance of using 2019 city data remains a concern, but the 62% Pearson correlation with 2024 country-level SDG scores.

**Table 25** suggests that city trends would mirror national patterns. EU reports indicate significant progress in SDG 8 (Decent Work) but continued lags in environmental SDGs, with moderate setbacks in SDG 7 (Clean Energy) and SDG 15 (Life on Land), and only mild progress on SDG 13 (Climate Action). This suggests that if 2024 city data were available, it would likely show an even starker disparity between economic and environmental outcomes.

### 4.6 Strengths and Limitations of the SYNERGISE+ Model

A key advantage of the SYNERGISE+ framework is its qualitative evaluation capability, which ensures that actions lacking precise financial or quantitative data are still considered in decision-making. Rather than requiring exact numerical inputs, the framework allows decision-makers to estimate the relative impact of an action compared to others. This implies that actions with incomplete, non-existent, or uncertain data are not automatically excluded but can still be evaluated based on expert judgment and contextual relevance. SYNERGISE+ qualitative nature is particularly valuable in climate and sustainability planning, where many adaptation and mitigation actions involve long-term, indirect, or non-monetary benefits that are difficult to quantify. By allowing decision-makers to compare the relative importance of different actions, SYNERGISE+ ensures a more comprehensive and inclusive evaluation process, preventing valuable but under-documented actions from being overlooked.

SYNERGISE+ includes the often omitted technical and institutional dimensions, ensuring SECAP actions are not only sustainable but also achievable and aligned with the city's goals. Research highlights that a city's ability to implement sustainability actions depends on its investment attractiveness, financing access, and project execution capacity (Spyridaki *et al.*, 2020). Without structured financial and institutional support, many initiatives remain aspirational. To address this, SYNERGISE+ includes ROI and Implementation and Management Complexity to assess economic viability, while Political and Legal Framework and Political Acceptability ensure governance alignment. This structured, and original, approach bridges the gap between planning and implementation, ensuring SECAP priorities are both impactful and actionable.

The model successfully captures implicit sustainability priorities by using a structured, multi-criteria decision analysis approach. The pairwise comparison weight elicitation aligns well with established MCDA methods like PAPRIKA, confirming its robustness and reliability through a simple method. By testing real-world SECAPs, the model demonstrates its applicability to existing urban planning frameworks.

While SYNERGISE+ provides a powerful framework for prioritising urban sustainability actions, certain challenges and limitations remain. The primary limitation of the model is its inability to explicitly account for uncertainty—both in terms of the likelihood of climate risks occurring and the effectiveness of selected climate actions. It assumes that all actions derived from an existing sustainability plan, such as a SECAP, have already undergone a thorough risk and vulnerability assessment. A deliberate methodological choice was made to prioritize usability and decision-making transparency over incorporating advanced uncertainty modelling. Existing tools that account for uncertainty tend to be highly complex, requiring extensive data inputs and technical expertise, which can hinder their practical application for local decision-makers. By streamlining the framework, SYNERGISE+ ensures accessibility and ease of use while still providing a structured and comprehensive evaluation of mitigation and adaptation actions. Nonetheless, future iterations could explore ways to integrate simplified uncertainty assessments without compromising the model's usability.

Additionally, potential biases are possible in weight elicitation: Although the model ensures a structured decision-making process, stakeholders' subjective preferences may still introduce bias. Conducting sensitivity analyses on weighting choices, or creating a common value-scenario based on a pattern across similar European cities could further enhance decision robustness. Finally, while SYNERGISE+ allows for cost considerations, a more advanced financial model could improve budget optimization within SECAPs. Addressing these limitations will be critical for further refining the decision-support capabilities of SYNERGISE+, ensuring that it remains a practical and adaptable tool for urban planners.

Overall, the results demonstrate that decision-making in SECAPs is influenced by both explicit and implicit priorities, often favouring political feasibility over sustainability outcomes. The SYNERGISE+ framework provides a structured method to uncover and realign these priorities, offering a data-driven approach to sustainable urban planning. As cities move toward more ambitious climate targets, tools like SYNERGISE+ will be essential in ensuring that sustainability commitments translate into actionable, well-prioritized strategies.

While the strengths of the SYNERGISE+ methodology are clear, certain limitations—particularly in relation to the SDG alignment and scenario validation—are addressed more fully in the concluding chapter (Section 5.1), where their implications for generalisability and future research are discussed.

### 4.7 Policy and Decision-Making Implications

This study underscores the importance of structured decision-support tools in urban sustainability planning and assesses whether SYNERGISE+ can accurately capture implicit urban priorities, reveal underlying motivations, and provide meaningful recommendations to enhance urban sustainability planning. While SECAPs serve as essential instruments for guiding climate strategies, their implementation is often constrained by institutional feasibility and economic limitations, sometimes at the expense of long-term sustainability benefits. The SYNERGISE+ framework addresses these challenges by offering a holistic decision-making tool that integrates mitigation and adaptation actions within a unified prioritization model.

Unlike traditional approaches, which often rely on external consultants or expert-driven methods, SYNERGISE+ enables municipalities to make informed decisions autonomously, reducing reliance on external expertise while maintaining a structured and objective evaluation process. Additionally, by consolidating all aspects of sustainability planning in a single framework, SYNERGISE+ enhances transparency and ease of decision-making, helping local governments systematically align their strategies with their actual priorities.

One of the key advantages of SYNERGISE+ is its ability to uncover implicit city values, providing insights into whether sustainability planning is primarily motivated by environmental, economic, or political considerations. This also enables an important corrective mechanism, allowing municipalities to reassess and adjust their SECAPs based on structured value-based assessments, as was shown through successful application to three existing SECAPs.

The results indicate that institutional feasibility and economic viability are consistently ranked as top priorities in SECAPs, while environmental and social factors are often deprioritized. This suggests that cities tend to structure their sustainability plans based on political and administrative feasibility rather than prioritising long-term climate benefits. Furthermore, cities are not fully utilising the synergy potential between mitigation and adaptation actions, leading to inefficiencies in implementation and resource allocation.

These findings have important implications for urban sustainability planning and how SECAPs are developed. The dominance of institutional and economic considerations over sustainability outcomes suggests that local governments may not be maximising the long-term benefits of mitigation and adaptation actions and are overlooking opportunities to maximize social and environmental benefits. To address this, three key recommendations emerge from this analysis:

- Enhancing Value-Based Decision-Making: Cities should explicitly define their sustainability priorities and use MCDA tools like SYNERGISE+ to ensure that economic and political feasibility does not overshadow environmental and social benefits. The current reliance on financial viability as a key decision driver may result in short-term cost savings at the expense of long-term sustainability. Often, environmental factors are economic in nature and labeling them as such might skew our perception of progress, as illustrated in a separate publication on evaluating Sustainable Development Goals progress through SYNERGISE+ criteria.
- Optimising SECAP Planning for Synergies: The model identified that, on a limited sample of three cities, over 80% of SECAP actions have synergy potential, yet cities are not systematically integrating these opportunities. A stronger synergy-driven approach could lead to substantial cost savings if synergies were leveraged effectively.
- Periodic Reassessment of SECAP Priorities: The dynamism of sustainability planning means that city priorities will evolve over time. SECAPs should not be treated as static plans but rather as living documents that are periodically reassessed using structured MCDA models like SYNERGISE+.

### 4.7.1 Implications for achieving the SDGs

While the classification into balanced, sustainable, technocratic, and conventional scenarios provides a structured view of urban sustainability, the mechanisms through which cities transition between these scenarios require further exploration. Cities categorized as ‘technocratic’ or ‘conventional’ may enhance sustainability by adopting integrated governance models, investing in green infrastructure, and prioritizing policy coherence between economic and environmental strategies. Conversely, *sustainable* cities must continuously innovate to maintain resilience and avoid stagnation due to policy inertia.

What is clear, however, is that at the national level, efforts within the technical dimension serve as a strong driver of success. This suggests that cities seeking to transition toward more sustainable scenarios should prioritize technological advancements, institutional capacity-building, and data-driven decision-making. Future research should assess the drivers of scenario shifts, such as policy interventions, external shocks, or investment patterns, to provide a clearer roadmap for cities aiming to achieve more balanced and sustainable urban models.

### 4.7.2 Optimising synergies

Optimizing SECAP Planning for Synergies: The model identified that, on a limited sample of three cities, over 80% of SECAP actions have synergy potential, yet cities are not systematically integrating these opportunities. A stronger synergy-driven approach could lead to substantial cost savings if synergies were leveraged effectively.

By embedding value-driven decision-making, ensuring synergy integration, and regularly reassessing priorities, municipalities can align SECAPs more effectively with long-term climate resilience and sustainability objectives. To institutionalize synergy-based planning, municipalities could integrate a mandatory synergy assessment into their SECAP review process, ensuring that co-benefits between adaptation and mitigation actions are systematically evaluated. Additionally, financial incentives could be introduced to encourage cross-sectoral collaboration, maximising efficiency in urban sustainability investments.

# 5. Conclusion

This dissertation set out to explore how local and regional governments can make more informed decisions when prioritising sustainable climate actions—particularly within the context of Sustainable Energy and Climate Action Plans (SECAPs). By developing and applying the SYNERGISE+ decision-support framework, the research demonstrates that a structured, value-based methodology can significantly improve the way urban climate actions are selected, ranked, and aligned with long-term goals.

The SYNERGISE+ framework integrates five dimensions of sustainability—environmental, economic, social, technical, and institutional—and supports participatory weight elicitation from local stakeholders. This approach enables cities to prioritise mitigation and adaptation actions not based solely on short-term feasibility or political convenience, but on the values and development objectives relevant to their context.

Through multiple applications across three European cities and two model scenarios, the research confirms the main hypothesis (H0): that a structured, value-based tool integrating both climate dimensions can enhance resource allocation by revealing synergies and co-benefits in urban sustainability planning. Moreover, the analysis supports several key findings:

- Most existing tools and plans do not systematically evaluate mitigation and adaptation together (H1, H5).
- Participatory methods such as pairwise comparison can effectively capture stakeholder preferences without sacrificing clarity or rigour (H2).
- When local preferences are explicitly incorporated into scoring models, action prioritisation becomes more aligned with the city's strategic goals (H3).
- In practice, economic and political feasibility tend to dominate decision-making, while environmental and social aspects are often undervalued (H6).

While the primary focus of this research is methodological and decision-oriented, the study also tested the wider relevance of the SYNERGISE+ framework by aligning it with the Sustainable Development Goals (SDGs). This comparative analysis across 45 EU cities and 167 countries illustrates that the SYNERGISE+ dimensions are broadly compatible with global sustainability agendas and can be used to identify systemic imbalances in how goals are pursued. The findings reaffirm the dominance of economic indicators in sustainability performance (H4) and show that even high-scoring cities may prioritise economic viability at the expense of long-term environmental outcomes.

Crucially, this research offers more than just a tool—it proposes a decision-making philosophy based on clarity, transparency, and the contextualisation of sustainability choices. By moving away from fragmented, checklist-based planning toward integrated, stakeholder-driven evaluation, SYNERGISE+ helps bridge the gap between political ambition and implementation feasibility. It empowers cities to prioritise actions that are not only cost-effective but also resilient, inclusive, and forward-looking.

In sum, the dissertation contributes both theoretically and practically to the field of urban sustainability planning. It provides a replicable framework that supports more informed decisions under uncertainty and strengthens the capacity of local governments to implement sustainable actions that are coherent, synergistic, and aligned with their community's values.

### 5.1 Recommended Policy Actions

Based on the findings of this research, several policy actions are recommended to strengthen sustainability planning and improve the prioritisation of urban climate actions. These actions are grouped into five key areas:

I. Redefine Environmental Targets and Indicators

To promote more meaningful progress on sustainability goals, particularly in high-income regions, environmental targets must shift from soft, input-based indicators to outcome-driven, measurable goals. This research confirms that economic performance remains the dominant driver of current SDG success (H4), often overshadowing long-term environmental needs. Mitigation and adaptation strategies must be evaluated together, using rigorous frameworks that reflect real-world impact rather than symbolic commitments.

II. Strengthen Technical and Social Capacity

The success of sustainable action plans is closely tied to a city's technical readiness and social inclusiveness, as shown in both the SYNERGISE+ analysis and the extended SDG comparison. Investments in green technology, climate education, and social innovation programmes should be prioritised, particularly in lower-income settings. Development assistance should focus not only on financial support but on building institutional and technical capacities to reduce long-term disparities in climate performance.

III. Improve Alignment Between Local and National Planning

This study highlights inconsistencies between local planning priorities (e.g., in SECAPs) and national SDG performance. Regular city-level SDG assessments, grounded in locally relevant criteria, should be implemented to ensure that local climate actions are better aligned with national and global goals. SYNERGISE+ provides a practical methodology for such alignment by linking local actions with broader sustainability dimensions.

IV. Institutionalise Value-Based, Participatory Decision-Making

Governments at all levels should adopt structured, transparent decision-support tools—such as SYNERGISE+—to prioritise actions not only by cost or carbon impact but by stakeholder values and local feasibility. The pairwise comparison method tested in this study offers a simplified but rigorous approach to stakeholder engagement, enabling cities to tailor decisions to their unique context (H2, H3).

V. Promote Integrated, Synergistic Planning

Finally, policy frameworks should systematically address synergies between mitigation and adaptation, which are often overlooked (H5). The integration of both within a single decision model—as demonstrated in SYNERGISE+—can improve cost-efficiency, avoid duplication, and promote more holistic sustainability outcomes. This research illustrates that cross-sectoral planning, when paired with participatory tools, can support more coherent and resilient policy implementation.

This study underscores that achieving sustainability outcomes requires more than economic growth. It demands well-structured, participatory, and transparent planning processes that align actions with long-term environmental and social objectives. As cities pursue increasingly ambitious climate goals, adopting integrated decision-support frameworks like SYNERGISE+ will be essential to translating high-level commitments into concrete and effective local action. Future policy development should build on this foundation to advance coherent, fair, and efficient pathways to sustainability.

## 5.2 Study Limitations

While this research makes a substantial methodological and practical contribution to urban climate planning, a number of limitations must be acknowledged—primarily affecting one specific component of the study. As outlined in Subchapter 4.6, the SYNERGISE+ framework demonstrates several methodological strengths, particularly its capacity to support participatory and integrated decision-making. Nonetheless, certain limitations—especially those related to the SDG alignment analysis—remain and are elaborated below to clarify the scope and generalisability of the findings.

First, only the SDG-alignment validation segment of the study—which compares the SYNERGISE+ framework with SDG performance data—relies on cross-sectional data from 2019. This introduces certain limitations related to data collection methodologies, potential inconsistencies, and the lack of updated or dynamic performance metrics. As this dataset reflects a single point in time, it limits the ability to track the evolution of urban sustainability trajectories. A longitudinal approach would offer a more comprehensive picture of how cities' sustainability performance develops over time. However, the dataset used represents the most comprehensive and publicly available source of city-level SDG data, and significant effort was made to critically assess and align the underlying SDG indicators with the SYNERGISE+ sustainability dimensions. Importantly, this limitation only affects one analytical conclusion of the study, and does not undermine the validity of the broader SYNERGISE+ framework or its main applications.

Second, as SDG data were available only for European cities, the generalisability of the SDG mapping analysis to other global regions—especially low- and middle-income countries facing different urban challenges—remains limited. Future research should explore the applicability of the SYNERGISE+ framework across a broader set of geographical contexts and governance conditions.

Third, while the classification of cities into four planning scenarios—balanced, sustainable, technocratic, and conventional—offers valuable insights into planning typologies, cities that fall outside these categories were not examined in detail. Future refinements could identify hybrid or transitional city types, which would further enhance the framework's adaptability and explanatory power.

Lastly, this study intentionally excluded the influence of external shocks, such as the COVID-19 pandemic or macroeconomic disruptions. Since the primary datasets were compiled before or shortly after these events, their long-term structural impacts on sustainability performance were not within the study's scope. Further investigations are needed to evaluate how such shocks may alter prioritisation logic or reshape decision-making dynamics in the long term.

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# 8. List of Tables

# 9. List of Figures

# 10. Appendix

**Appendix A: A detailed comparative overview of SYNERGISE+ and 13 existing dominant sustainable indices**

**Table A.1:** A detailed comparative overview of SYNERGISE+ environmental impact and economic viability dimensions with 13 existing dominant sustainable indices.

| | **ENVIRONMENTAL IMPACT DIMENSION** | | | **ECONOMIC VIABILITY DIMENSION** | | |
|---|---|---|---|---|---|---|
| **SYNERGISE+** | Emission reduction and resource efficiency | Biodiversity conservation | Risk and vulnerability | Return on investment | Economic impact | Implementation and management |
| **CDP ICLEI Track** | Reduced: GHG emissions; natural resource depletion; disruption of energy, transport, water or communications networks. Increased energy security. Improved: waste mngmt; water/soil quality. | Protected/improved biodiversity and ecosystem services; Reduced noise/light pollution; Improved air quality. | Reduced disaster/disease/contamination-related health impacts. | Reduced costs; revenue generation. | Job creation; increased energy security; improved labor conditions. | |
| **EBRD GCAP** | Water, energy, land and material use; | Air, water, soil quality; Biodiversity | Climate change adaptation | Economic returns for investor | Economic growth; Employment | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Climate change mitigation | | | | | |
| **ECPI** | Reduction of GHG emissions and energy intensity. | | | | Employment; security of energy supply. | Compliance costs, governmental revenues, administration costs, transaction costs. |
| **EUGCI** | Over 14 emission reduction and resource efficiency indicators. | Green land use policies. | Water system leakages. | | | |
| **InSMART FP7** | Energy and emission reduction potential and savings. | | | Cost-efficiency and financial effort associated with implementation; revenue production. | Local development and job creation. | Operational and maintenance cost, easiness of implementation. |
| **Life SEC ADAPT** | Reduced pollution and GHG emissions | Protection of natural resources; contribution to biodiversity | Reduction of vulnerability | Economic efficiency | Job creation | Implementation |

| | | |
|---|---|---|
| **PROSPECT City Capability Assessment** | GDP per capita; GDP growth rate; annual city expenditure & revenues; city revenues; city debt; nominal bank lending rate; tax rate for corporations; city population; unemployment rate | Municipality personnel for: funding options investigation; project underwriting; administration; co-ordination, and monitoring. Project: selection and prioritization process; underwriting and evaluation capacity. Ability to employ/train personnel to support project underwriting. Available personnel training schemes; established M&V procedure; operational standards/QA |

| | | | | | | |
|---|---|---|---|---|---|---|
| **RFSC** | Mitigate climate change; Manage natural materials, resources sustainability and prevent waste; Protect, preserve and manage water resources; Develop sustainable urban planning and land use; Stimulate green growth and circular economy. | Protect, restore and enhance biodiversity and ecosystems; reduce pollution. | Adapt to climate change; ensure territorial resilience. | | Develop employment and a resilient local economy. | Implement a process for assessment and continuous improvement. |
| **SDG EU Cities** | 7: Affordable and clean energy | 14[1]: Life below water; 15[1]: Life on Land | 13: Climate action | | 8: Decent work and economic growth | |
| **SDEWES** | CO2 emissions and Industrial profile; Energy Usage and Climate; Penetration of Energy and $CO_2$ Saving Measures; RE potential and utilisation. | Water Usage and Environmental Quality | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Smart Florence Plan** | Reduction in CO2 emissions and primary energy use per sector | Noise pollution reduction | Resiliance to natural disasters | | | Smart meters coverage |
| **Smart and Sustainable City Assessment** | CO 2 emissions; share of renewable energy; domestic water consumption | PM 10 average annual concentrations; amount of municipal waste | | | GRP; consumer price inflation rate; unemployment rate | |
| **SSI - Smart and Sustainable Index** | Greenhouse gases, energy savings, renewable energy, energy use; renewable water resources | Biodiversity, organic farming, sufficient food, drinking water, safe sanitation | | Genuine savings | GDP, public debt, employment | |

**(1)** Not applicable to the subnational (city) level as per (Lafortune *et al.*, 2019) methodology

**Table A.2**: A detailed comparative overview of SYNERGISE+ social equity, technical feasibility and competitiveness and institutional framework dimensions with 13 existing dominant sustainable indices.

| SYNERGISE+ | **SOCIAL EQUITY** | | **TECHNICAL FEASIBILITY & COMPETITIVENESS** | | **INSTITUTIONAL FRAMEWORK** | |
|---|---|---|---|---|---|---|
| | Equality /equity and accessibility | Quality of life and public health | Technological maturity and recycling potential | Innovation and learning potential | Political and legal framework | Political acceptability |
| **CDP ICLEI Track** | | increased/improved green space; improved mental wellbeing/quality of life; improved physical health. | | | Increased transparency and accountability. | |
| **ECPI** | | | | Increased environmental awareness; competitiv.s & technology: innovation cycle, diffusion of existing technologies, industrial competitiveness, market competition, business opportunities & trade. | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **EBRD Green City Action Plan Methodology** | Economic inclusion; Gender equality; Access to basic services (public transport, energy, water, solid waste collection, green spaces) | Safety; Public health; Green behaviour and awareness | | | | Community involvement |
| **EUGCI** | | Congestion reduction policies; green and non-car transport. | Energy efficienct building standards. | | | Public participation in green policy. |
| **InSMART FP7** | | Aesthetics/architectonic integration; improving comfort and quality of life of residents. | Technical constraints (scale of the technical issues associated with the scenario). | Improved education and public awareness on climate issues; business/technological innovation. | Legal and regulatory risks, barriers and concerns effecting the implementation of a scenario. | Level of societal acceptance. |
| **Life SEC ADAPT** | Reduction of inequality | Improved health; protection of heritage resources | | | | Urgency of implementation |

PROSPECT City Capability Assessment

| | | |
|---|---|---|
| City experience on sustainable energy projects | Available incentives for private project investors; Legal/regulatory constraints; efficient process for permit; public procurement procedures facilitation; ownership issues hinder sustainable energy projects; annual city budget for se projects; sufficiently exploited budget; available fin. support schemes; applied citizens' finance; cooperation/ communication with: other cities; public actors; | Public stance; initiatives disseminated |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | traditional & non-traditional private actors. |
| **RFSC** | Improve inclusive education and training; ensure: social, spatial, intergenerational equity and inclusion; increase citizen participation; housing for everyone; develop alternative and sustainable mobility; ensure spatial equity. | Promote culture and leisure opportunities; protect and promote health and well being; promote high quality and functionality of public spaces and living environment; preserve and enhance architectural, cultural , urban heritage. | | Promote innovation and smart cities; strengthen governance in partnership; facilitate capacity building and networking; foster cooperation and innovative partnerships; ensure connectivity. | Foster sustainable administration; encourage sustainable production and consumption; ensure integrated terrirotial strategy. |
| **SDG EU Cities** | 1: No poverty; 2: Zero hunger; 5: Gender equality; 10: Reduced inequalities | 3: Good health and well-being; 4: Quality education; 6: Clean water and sanitation | | 9: Industry, innovation and learning potential; 11: Sustainable cities and communities | 12: Responsible consumption & production; 16: Peace, justice, & strong institutions; 17: Partnerships for the goals |

| | | | | | |
|---|---|---|---|---|---|
| **SDEWES** | | Urban planning and social welfare; | Penetration of energy and $co_2$ saving measures | R&D, innovation, and sustainability policy | |
| **Smart Florence Plan** | 'Ensuring basic needs: sufficient food, drinking water, safe sanitation. Personal development: education, healthy life, gender equality. | Percentage of buildings under refurbishment according to EPBD standard | | | |
| **Smart and Sustainable City Assessment** | Gini index of income inequality | Life expectancy at birth; share of population aged 25–64 with higher education | Municipal solid waste recycling rate; average broadband internet speed; number of underground stations | Number of patents per 1000 inhabitants; creative industry employment rate | |
| **SSI Smart & Sustainable** | Access to education, gender equality, income distribution | Healthy life, population growth | | | Good governance |

**Appendix B: Description of SYNERGISE+ criteria and dimensions**

SYNERGISE+ index comprises five dimensions with twelve subcriteria, as follows:

**Dimension 1 – Environmental Impact**: Assesses actions based on their potential to reduce emissions and conserve biodiversity. Subcriteria of the environmental dimension:

1. Emission reduction and resource efficiency: Potential to reduce GHG through decreased use of resources like water, energy, land, raw materials. Reduced natural resource depletion, reduced disruption of energy, waste, transport, water or communications networks. Low carbon energy generation, increased energy efficiency, reduction of energy intensity.

2. Biodiversity conservation: Impact on local ecosystems and biodiversity, ability to protect, restore and enhance biodiversity and ecosystems through, for example, pollution control (reduced air, water, soil, noise, waste and light pollution).

3. Risk and vulnerability: Vulnerability Reduction (ability to reduce climate change risks), increase of adaptability (capacity to adjust to climate impacts) and long-term sustainability (resilience for long-term environmental changes). Disaster Risk Management (effectiveness in managing/mitigating natural disasters. contamination, disease).

**Dimension 2 – Economic Viability:** Evaluates actions based on economic returns, such as job creation and energy security. Subcriteria of the economic dimension:

4. Return on investment: Financial returns and payback periods, reduced costs.

5. Economic impact: Overall effect on local economy including job creation, labor productivity, increased economic production, energy security and business development and inward investment.

6. Implementation and management: Required time for deployment and implementation. Complexity of overseeing and managing the initiative. Ease of ongoing management, operation and maintenance. Dependency on external factors e.g., market conditions, technological advances. Monitoring and evaluation, including smart meters.

**Dimension 3 – Social Equity**: Assesses actions for their impact on social inclusion and quality of life. Subcriteria of the social dimension:

7. Equality /equity and accessibility: Human rights, including workers' rights, fair distribution of benefits and burdens, inclusive development; increased social inclusion, equality and justice; Stakeholder Engagement: Involvement of communities and stakeholders in decision-making, Fewer or no households and businesses forced from homes/places of work, ensuring spatial equity.

8. Quality of life and public health: Citizen's health and mental wellbeing and quality of life through reduced traffic congestion, increased indoor thermal

comfort, improved road safety and local environment, greening urban areas, reduced health impacts from extreme heat or cold, protection of cultural assets.

**Dimension 4 – Technical Feasibility & Competitiveness**: Evaluates technological readiness and scalability. Subcriteria of the technical dimension:

9. A) Technological maturity and recycling potential: Readiness level of the technology, or other technical constraints (scale of technical issues associated with the scenario);

B) Scalability: Ability to scale for broader implementation.

C) Flexibility: Adaptability to changing conditions and needs. Technology readiness level, or other technical constraints (scale of the technical issues associated with the scenario).

D) Ability of recycling and dismantling the technology after lifetime.

10. Innovation and learning potential:
    A) Knowledge Transfer: Opportunities for raising awareness, learning and capacity building;
    B) Innovation Potential: Potential to stimulate new innovative solutions;
    C) Research and Development: Opportunities for further R&D of best practices.

**Dimension 5 – Institutional Framework**: Focuses on the alignment of actions with political goals and legal frameworks. Subcriteria of the institutional dimension:

11. Political and legal framework: Legal and regulatory risks, barriers and concerns effecting the implementation of a scenario, compliance to existing laws. Includes EU Taxonomy objectives of bribery/corruption, taxation, fair competition.
12. Political acceptability: Level of political support and feasibility, relevance to local circumstances, social acceptability of a scenario to local citizens, policy synergies, i.e. alignment with existing policies and frameworks. Urgency of Implementation or time criticality.

## Appendix C: Results of the scenario sensitivity analysis

Table C.1 Results of the scenario sensitivity analysis.

| Tested cities: | City of Maribor, Slovenia | City of Zagreb, Croatia | City of Litoměřice, Czechia | Model city A - Conventional | Model city B - Sustainable | Average |
|---|---|---|---|---|---|---|
| Conventional vs. Balanced scenario | Balanced | Balanced | Conventional | Conventional | Sustainable | |
| Rank distribution: % of actions changing rank from Balanced to Conventional | 87% | 74% | 70% | 73% | 80% | 77% |
| Average number of rank change | 5 | 3 | 3.7 | 5 | 6 | 4 |
| Out of that, the average number of rank promotion | 5 | 3 | 5 | 5 | 6 | 5 |
| Out of that, the average number of rank demotion | -6 | -5 | -5 | -4 | -5 | -5 |
| Rank consistency: % of actions from top 10 that stayed in top 10 | 80% | 100% | 90% | 90% | 70% | 86% |
| Rank consistency: % of actions from top 20 that stayed in top 20 | 90% | 80% | 90% | 80% | 80% | 84% |
| Sustainable vs. Balanced scenario | | | | | | |
| Rank distribution: % of actions changing rank from Balanced to Sustainable | 89% | 79% | 68% | 70% | 93% | 80% |
| Average number of rank change | 6 | 3 | 8 | 4 | 6 | 5 |
| Out of that, the average number of rank promotion | 7 | 3 | 8 | 4 | 5 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Out of that, average number of rank demotion | -6 | -3 | -9 | -4 | -5 | -5 |
| Rank consistency: % of actions from top 10 that stayed in top 10 | 90% | 90% | 40% | 80% | 80% | 76% |
| Rank consistency: % of actions from top 20 that stayed in top 20 | 85% | 95% | 75% | 85% | 75% | 83% |
| Sustainable vs. Conventional scenario | | | | | | |
| Rank distribution: % of actions changing rank from Conventional to Sustainable | 82% | 82% | 79% | 81% | 81% | 81% |
| Average number of rank change | 8 | 4 | 10 | 7 | 7 | 7 |
| Out of that, average number of rank promotion | 6 | 5 | 11 | 7 | 4.9 | 7 |
| Out of that, the average number of rank demotion | -8 | -3 | -10 | -6 | -8 | -7 |
| Rank consistency: % of actions from top 10 that stayed in top 10 | 70% | 90% | 40% | 70% | 60% | 66% |
| Rank consistency: % of actions from top 20 that stayed in top 20 | 75% | 85% | 75% | 75% | 85% | 79% |

**Appendix D: Appropriation of SDGs into SYNERGISE+ dimensions**

| SDG No. | SDG title and description | SYNERGISE+ dimension and criteria |
|---|---|---|
| 1 | No poverty: ending poverty in all its forms everywhere; | SOCIAL EQUITY: Equality /equity and accessibility |
| 2 | Zero hunger: ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture; | |
| 3 | Good health and well-being: ensuring healthy lives and promoting well-being for all at all ages; | SOCIAL EQUITY: Quality of life and public health |
| 4 | Quality education: ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all; | |
| 5 | Gender equality: achieving gender equality and empowering all women and girls; | SOCIAL EQUITY: Equality /equity and accessibility |
| 6 | Clean water and sanitation: ensuring availability and sustainable management of water and sanitation for all; | SOCIAL EQUITY: Quality of life and public health |
| 7 | Affordable and clean energy: ensuring access to affordable, reliable, sustainable, and modern energy for all; | ENVIRONMENTAL IMPACT: Emission reduction and resource efficiency |
| 8 | Decent work and economic growth: promoting sustained, inclusive and sustainable economic growth, full and productive employment & decent work for all; | ECONOMIC VIABILITY: Economic impact |
| 9 | Industry, innovation, and infrastructure: building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation; | TECHNICAL FEASIBILITY & COMPETITIVENESS: Innovation and learning potential |

| | | |
|---|---|---|
| 10 | Reduced inequalities: reducing inequality within and among countries; | SOCIAL EQUITY: Equality /equity and accessibility |
| 11 | Sustainable cities and communities: making cities and human settlements inclusive, safe, resilient, and sustainable; | TECHNICAL FEASIBILITY & COMPETITIVENESS: Innovation and learning potential |
| 12 | Responsible consumption and production: ensuring sustainable consumption and production patterns; | INSTITUTIONAL FRAMEWORK: Political and legal framework |
| 13 | Climate action: taking urgent action to combat climate change and its impacts; | ENVIRONMENTAL IMPACT: Risk and vulnerability |
| 14 | Life below water: conserve and sustainably use the oceans, seas and marine resources for sustainable development; | ENVIRONMENTAL IMPACT: Biodiversity conservation |
| 15[1] | Life on land: protecting, restoring, and promoting sustainable use of terrestrial ecosystems, managing forests, combating desertification, and halting and reversing land degradation and halting biodiversity loss; | |
| 16 | Peace, justice, and strong institutions: promoting peaceful and inclusive societies for sustainable development, providing access to justice for all, and building effective, accountable and inclusive institutions at all levels; | INSTITUTIONAL FRAMEWORK: Political and legal framework |
| 17[1] | Partnerships for the goals: strengthen the means of implementation and revitalize the global partnership for sustainable development; | |

**(1)** Not applicable to the subnational (city) level as per (Lafortune *et al.*, 2019) methodology

**Appendix E: List of Action Clusters**

| Action bundle name | Type of action | Mitigation/ Adaptation/ Energy poverty | Affected sectors | Climate impacts |
|---|---|---|---|---|
| Adaptive management/functional connectivity of natural habitats & ecological networks | Policy | A | Nat, WW | Dr, ET, Fl, I&S, SLR, St, WS |
| Awareness campaigns for behavioural change | Awareness | M, A | Buil, En | ET |
| Bioenergy and hydrogen in transport (i.e. switching garbage collection vehicles to biofules, or at farm level) (RES) | Infrastructure | M | En, Nat, Tr, WW | |
| Building refurbishment incl. roof, solid walls and window insulation, and aditional climate proofing against excessive heat (i.e. green rooftops, shade systems, roof albedo enhancement or cool roofs) | Infrastructure | M, A | Buil, DRR | ET |
| Capacity building on climate change adaptation and mitigation | Awareness | M, A | Buil, DRR, En, Nat, Tr, WW | Dr, ET, Fl, I&S, SLR, St, WS |
| Carbon capture, transport, utilisation and storage (CCS) in cities | Infrastructure | M | En, WW | |
| Carbon tax of production, distribution, or consumption of non-renewable energy | Financial | M | En | |
| Coastal zone management (beach nourishment, flood | Natural | A | DRR | Fl, SLR, St |

| | | | | |
|---|---|---|---|---|
| barriers, cliff stabilisation,restoration of wetlands, retreat form high-risk areas) | | | | |
| Combined energy (other than RES) - co-firing of biomass and wastes, combined heat and power (CHP) systems, or district heating/cooling networks | Infrastructure | M | Buil, En, WW | |
| Conservation/low-carbon agriculture (innovative crop management, manure spreading and storage, precision agriculture, nitrogen balance) | Natural | A, M | Nat | Dr, ET, WS |
| Crises and disaster management systems and plans (incl. fire and flood) | Policy | A | Buil, DRR, Nat, Tr | Dr, ET |
| Developing greenhouse gas inventory | Policy | M | En | |
| Economic incentives for behavioural change or private sector's climate innovation, adaptation and improved environmental quality | Financial | M, A | En, Nat, Tr, WW | Dr, ET, Fl, I&S, SLR, St, WS |
| Electric transport/mobility (EV charging stations at home and public, bycycle lanes and parking) | Infrastructure | M | En, Tr | |
| Enhanced Waste & Wastewater Resource Recovery | Technological | M, A | WW | WS |
| Establishment of early warning systems/plans | Policy | A | Buil, DRR, En, | Dr, ET, Fl, I&S, St, WS |

| | | | | |
|---|---|---|---|---|
| | | | Nat, Tr, WW | |
| Feed-in-tarifs, subsidies, tax reductions and loans for renewable energy systems (RES) and purchasing energy saving (EE) equipment | Financial | M | En | |
| Heat health action plans and response to heatwaves (incl. heat mapping, thermal imaging, using water to cope with heatwaves) | Policy | A | DRR, Tr, WW | ET |
| Improving adaptability of large infrastructure (i.e. airports, energy distribution and transmission infrastructure, groundwater management) | Infrastructure | A | Buil, DRR, En, Tr, WW | Dr, ET, Fl, I&S, SLR, St, WS |
| Insurance as risk management tool (incl. weather derivatives) | Financial | A | DRR | ET, I&S, St |
| Integrated urban energy systems - incl. traffic and road management plan (adaptation solutions such as floating or elevated roads) | Policy | M, A | DRR, Tr, En | Fl, SLR, St |
| Integration of adaptation in nature-based plans (coastal zone management, land use, drought and water conservation plans) | Policy | A | DRR, Buil, Nat, WW | Dr, ET, Fl, I&S, SLR, St, WS |

| | | | | |
|---|---|---|---|---|
| Introducing congestion charges and pricing, road charges and tolls | Financial | M | DRR, Tr | |
| Investing in climate smart urban agriculture (urban green actions, new green spaces incl. green roofs,xeriscaping) | Natural | A, M | Nat | ET, Fl, WS |
| Management plans for coastal areas and aquaculture (i.e. risk-based zoning/siting for marine aquaculture, diversification of fisheries and aquaculture products and systems) | Policy | A | Nat | ET, SLR, St |
| Meters/decetors for intelligent lighting systems (i.e. automatisation of building lighting, or street lighting part-night operation, trimming and remote monitoring) | Technological | M | En, Buil | |
| Motivational campaigns about climate smart urban agriculture (urban green actions, new green spaces incl. green roofs) | Awareness | M, A | Buil, DRR, Nat, WW | |
| Municipal street and traffic lighting retrofit programme | Infrastructure | M | En | |
| Plan to alleviate energy poverty | Policy | M, EPov | Buil, En | |
| Prescription of quota system for renewable energy production and renewable obligation for households/SMEs | Policy | M | En | |

| | | | | |
|---|---|---|---|---|
| Reduction/savings of electricity and fuel - other than RES and structural refurbishment (i.e. EE, phasing out inneficient technologies, setting up a Building Management System) | Technological | M, A | Nat, En, Buil, WW | Dr, ET |
| RES in buildings - PV, solar thermal, energy for cooking/heating incl. condensing boilers, biomass briquettes, heat pumps, geothermal | Technological | M | Buil, En | |
| Retrofitting and replacing inefficient vehicle fleet | Infrastructure | M | Tr | |
| River and floodplains management (establishment/restoration of riparian buffers, flood barriers,dunes) | Natural | A | DRR, Nat, WW | Dr, ET, Fl, SLR, St |
| Stricter standards and regulations for building new and refurbishing existing buildings | Policy | M, A | Buil | |
| Subsidies for low-carbon transport (bike to work program, rail transport subsidies, carpooling) | Financial | M | Tr | |
| Subsidies to alleviate energy poverty | Financial | M, A, EPov | Buil, En | |
| Sustainable soil and land management (afforestation, reforestation, agroforestry) | Natural | A, M | Nat | Dr, ET, Fl |
| Sustainable urban waste management and | Policy | M | En, WW | |

| | | | | |
|---|---|---|---|---|
| recycling and composting initiatives | | | | |
| Technical innovation in transport and modal shift (electrified transport) | Technological | M | En, Tr | |
| Urban green infrastructure plans and nature-based solutions (i.e. tree planting and creation of green spaces) | Policy | M, A | Buil, DRR, En, Nat, Tr, WW | ET, Fl, I&S, St, WS |
| Use of remote sensing in climate change adaptation | Technological | A | Nat, WW | Dr, ET, Fl, I&S, SLR, St, WS |
| Waste and wastewater structural projects, incl. decentralized systems for water-sewerage-energy infrastructure and deployment of recycling and composting infrastructure | Infrastructure | M | WW | |
| Other large RES incl. hydropower, geothermal, windpower, ground mount solar, waste to energy biomass plants (electricity generation only) | Infrastructure | M | En, Nat, WW | |
| Water reuse, restrictions and water rationing | Natural | A | En, Nat, WW, DRR | Dr, WS |
| Water sensitive forest management | Natural | A | DRR, Nat, WW | Dr, Fl, WS |
| Water sensitive urban and building design | Policy | A | Buil, DRR, WW | Dr, Fl, St, WS |

# 11. Resume

I was born on July 23rd 1986, in Osijek, Croatia. Since 2022, I have been living and working in Abu Dhabi.

I graduated from the Mathematics Gymnasium in Osijek and studied Tourism Management and Entrepreneurship at the Rochester Institute of Technology in Dubrovnik. Already during my university studies, I became interested in sustainability and chose smart homes as the topic of my final thesis.

I began my career at the United Nations Development Programme, working on the introduction of energy efficiency in public buildings in Croatia. Alongside work, I completed the first international MBA programme focused on energy efficiency and renewable energy delivered in cooperation between the Berliner Hochschule für Technik (BHT) and the Renewables Academy (RENAC).

Later, I contributed to the development of Croatia's energy efficiency policies. As one of the expert authors of the 3rd National Energy Efficiency Action Plan, the Regulation on Measurement and Verification of Energy Savings, and legal frameworks related to local energy planning and implementation of the EU Energy Efficiency Directive, I had an immense opportunity to learn about energy efficiency local policy.

After two additional years working at the Hrvoje Požar Energy Institute, in 2017 I joined the Netherland Institute for European Energy and Climate Policy (IEECP Stichting), where I spent seven years working on EU-funded projects aimed at the energy transition and a sustainable future. Through cooperation with cities and regions, I observed a disconnect between adaptation and mitigation planning, which often resulted in suboptimal climate outcomes and inefficient use of resources.

This led me to focus my research on the synergy between adaptation and mitigation, with the aim of connecting sustainable measures into more effective climate strategies. Within the Horizon 2020 project PROSPEC+, I developed SYNERGISE+ — a decision-support tool for prioritising investments in local sustainable plans — which is also the subject of this dissertation.

To date, I have published six scientific papers, the first three of which directly originate from this research:

Dragović Matosović, M, Exintaveloni, D.S., Pizzini, G. (2026). SYNERGISE+: A Value-Based Decision-Support Framework for Prioritizing SECAP Actions and Advancing Synergistic Sustainable Urban Planning. *Climate Policy*.

Dragović Matosović, M, Pizzini, G. (2026). A Structured Library of Local Climate and Energy Actions to Support Synergy-Oriented Sustainable Urban Planning. *Sustainability*.

Dragović Matosović, M, Cerović, Lj. (2025). Drivers of Sustainability: Economic vs. Environmental Priorities in SDG Performance. *Sustainable* Futures, 9, 100639. https://doi.org/10.1016/j.sftr.2025.100639

Dragović Matosović M., Matosović M. (2020). Economic Appraisal of Introducing Energy Efficiency in the Public Sector: Overview of Existing Economic Methods with Ex-post Application to Sustainable Energy Management Program in Croatia. In: Bertoldi P. (eds) Improving Energy Efficiency in Commercial Buildings and Smart Communities. Springer Proceedings in Energy. Springer, Cham. DOI: 10.1007/978-3-030-31459-0_5

Perreto, M., Eichhammer, W., Dragović Matosović, M., Spirydakos, S. (2025). Innovative index for quantifying and monitoring welfare changes resulting from the implementation of a fair energy transition in coal regions across the European Union. *Energy and Climate Change*. DOI: 10.2139/ssrn.5252551

Spyridaki, N.-A.; Kleanthis, N.; Tzani, D.; Matosović, M.D.; Flamos, A. (2020). A City Capability Assessment Framework Focusing on Planning, Financing, and Implementing Sustainable Energy Projects. *Sustainability* 2020, 12, 8447. DOI: 10.3390/su12208447

# 12. Životopis

Rođena sam 23. srpnja 1986. u Osijeku, a od 2022. živim i radim u Abu Dhabiju.

Završila sam Prirodoslovno-matematičku gimnaziju u Osijeku, a potom studirala Menadžment u turizmu i poduzetništvo na Rochester Institute of Technology u Dubrovniku. Još tijekom studija počela sam se zanimati za održive teme te sam za završni rad odabrala temu pametnih kuća.

Karijeru sam započela u Programu Ujedinjenih naroda za razvoj, radeći na uvođenju energetske učinkovitosti u javne zgrade u Hrvatskoj. Uz posao sam završila prvi međunarodni MBA program usmjeren na energetsku učinkovitost i obnovljive izvore energije – MBA Renewables and Energy Efficiency – u suradnji berlinskog tehničkog sveučilišta Berliner Hochschule für Technik (BHT) i akademije za obnovljive izvore RENAC.

Nakon toga sam sudjelovala u kreiranju politika energetske učinkovitosti u Hrvatskoj. Kao jedna od autorica 3. Nacionalnog akcijskog plana energetske učinkovitosti, Pravilnika za mjerenje i verifikaciju ušteda energije te pravnog okvira za lokalno energetsko planiranje i prenošenje obveza iz Europske direktive o energetskoj učinkovitosti, imala sam priliku puno naučiti o održivom planiranju lokalnih samouprava.

Nakon još dvije godine rada u Energetskom institutu Hrvoje Požar, 2017. godine zaposlila sam se u nizozemskom Institutu za europske energetske i klimatske politike (IEECP Stichting), gdje sam sedam godina bila zadužena za prijavu i koordinaciju EU projekata usmjerenih na energetsku tranziciju i održivu budućnost. U suradnji s gradovima i regijama primijetila sam razdvojenost planiranja mitigacije i adaptacije, što često rezultira slabijim klimatskim učincima i neučinkovitom potrošnjom resursa.

Zbog toga sam istraživački fokus usmjerila na sinergiju između adaptacije i mitigacije, s ciljem povezivanja održivih mjera u učinkovitiju provedbu klimatskih strategija. Unutar projekta Obzor 2020 PROSPECT+ razvila sam alat SYNERGISE+ za podršku odlučivanju i prioritizaciji ulaganja u mjere iz lokalnih održivih planova, koji je ujedno i predmet ove disertacije.

Do sada sam objavila pet znanstvenih radova, od kojih prva tri potječu direktno iz doktroskog istraživanja:

Dragović Matosović, M, Exintaveloni, D.S., Pizzini, G. (2026). SYNERGISE+: A Value-Based Decision-Support Framework for Prioritizing SECAP Actions and Advancing Synergistic Sustainable Urban Planning. *Climate Policy*.

Dragović Matosović, M, Pizzini, G. (2026). A Structured Library of Local Climate and Energy Actions to Support Synergy-Oriented Sustainable Urban Planning. *Sustainability*.

Dragović Matosović, M, Cerović, Lj. (2025). Drivers of Sustainability: Economic vs. Environmental Priorities in SDG Performance. *Sustainable* Futures, 9, 100639. https://doi.org/10.1016/j.sftr.2025.100639

Dragović Matosović M., Matosović M. (2020). Economic Appraisal of Introducing Energy Efficiency in the Public Sector: Overview of Existing Economic Methods with Ex-post Application to Sustainable Energy Management Program in Croatia. In: Bertoldi P. (eds) Improving Energy Efficiency in Commercial Buildings and Smart Communities. Springer Proceedings in Energy. Springer, Cham. DOI: 10.1007/978-3-030-31459-0_5

Perreto, M., Eichhammer, W., Dragović Matosović, M., Spirydakos, S. (2025). Innovative index for quantifying and monitoring welfare changes resulting from the implementation of a fair energy transition in coal regions across the European Union. *Energy and Climate Change*. DOI: 10.2139/ssrn.5252551

Spyridaki, N.-A.; Kleanthis, N.; Tzani, D.; Matosović, M.D.; Flamos, A. (2020). A City Capability Assessment Framework Focusing on Planning, Financing, and Implementing Sustainable Energy Projects. *Sustainability* 2020, 12, 8447. DOI: 10.3390/su12208447