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COLLECTION: MONITORING AND EVALUATION

PEER-REVIEWED PAPER

How can multiple impacts of energy efficiency policies be quantified?

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ABSTRACT

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Implementing energy efficiency policies remain a cornerstone to achieving energy and climate objectives across the EU. While energy efficiency measures result in wider benefits, these can be difficult to quantify as required by the revised Energy Efficiency Directive (EU/2023/1791) Article 3 (EED). The MICATool provides an online tool to effectively quantify the multiple impacts of energy efficiency policies and support national reporting to the EED. Using national showcases from Germany, this paper demonstrates how the MICATool can quantify and monetise the impacts for various social, economic and environmental indicators, e.g. the reduction in health impacts, alleviation of energy poverty, impacts on import dependence, employment and GDP, or reduction in additional generation capacity required. The national showcases focus on three energy efficiency programs targeted at different sectors (residential, transport, industry) giving a broader overview of the analysis of multiple impacts of energy efficiency as well as the implementation of the energy efficiency first principle. Using input data from existing ex-post evaluations of the measures in these programs for our analysis, the results demonstrate which wider benefits to society can be linked to each measure and how their respective monetisation can be assessed for a cost-benefit analysis. This paper demonstrates how the methodological framework of the MICATool can support a simplification for Member States to implement EE1st and reporting accordingly thereby enabling informed decision-making to find the most beneficial path to climate neutrality for society as a whole.

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INTRODUCTION

Investments in energy efficiency (EE) are necessary to achieve the objectives outlined in the revised Energy Efficiency Directive (EU/2023/1791). Therefore, Article 3 (EED), which designates the Energy Efficiency First (EE1st) principle, is a cornerstone of EU energy policy to support EE investments and to achieve annual energy savings (European Union 2023). The quantification of the multiple benefits (MB) or multiple impacts (MI) of energy efficiency (EE) is crucial to counteract the challenges of the uptake of EE investments regarding, for example, the high upfront costs and long payback periods, or the impact of rebound, (Berger et al. 2022; IEA 2014, 2025) and is essential when assessing and comparing investment alternatives, strategies, or policies designed to achieve energy and climate targets. Therefore, "in applying the energy efficiency first principle, Member States shall: (a) promote and, where cost-benefit analyses are required, ensure the application of, and make publicly available, cost-benefit methodologies that allow proper assessment of the wider benefits of energy efficiency solutions […]" (Art.3 5(a)).

MIs include a broad range of effects emerging from the implementation of EE measures often referred to as non-energy benefits or co-benefits, which include gains in employment, GDP, productivity, and energy security, as well as positive effects on health, ecosystems, and agricultural productivity (Thema et al. 2019; Berger et al. 2025). MIs are typically quantified through monetisation, aggregation of EE outcomes, and cost-benefit analyses (Reuter et al. 2020). While various methods have been developed to quantify the multiple impacts (MI) of EE and renewable energy (RE), (IEA 2014, 2025; Resch et al. 2016; Reuter et al. 2020; Breitschopf et al. 2016; Thema et al. 2019; Makešová and Valentová 2021) these methods typically necessitate sophisticated modelling techniques or utilise indicator frameworks that require substantial data inputs thereby restricting their applicability in situations where data access, specialist knowledge, or resources are limited. The need from a policy viewpoint is to be able to quickly and easily generate an assessment of the MIs in a simplified way to meet national and European reporting obligations such as the National Energy and Climate Plans (NECPs) as well as the respective progress reports (including e.g. the requirements of Art. 3 EED). A broader assessment of multiple benefits is essential to ensure that short term gains are not pursued at the expense of long-term objectives. A narrow focus on short-term gains may overlook wider impacts beyond energy and climate, including effects on health, employment, and air quality, and may therefore lead to less beneficial outcomes from a societal perspective. As a results, the incorporation of the analysis of MI of EE into decision-making (as outlined in Art. 3 EED) is essential to implement solutions which are most beneficial for society as a whole.

The **S**upport **E**nergy **E**fficiency **D**eployment with the **M**ultiple **I**mpacts **CA**lculation **Tool** (SEED MICATool) project assists the EU and member states at national, regional and local governance levels with the implementation of the EE1st principle by providing a comprehensive methodological framework for estimating the MIs of EE and RE measures through a publicly accessible, user-friendly online platform. The tool enables not only the use for scientific purposes but also supports policymakers and analysts to conduct streamlined assessments in their implementation of the EE1st principle. To demonstrate the application of the MICATool and quantify MIs in a policy-relevant context, this paper evaluates three German EE programmes under the EE1st principle. The analysis specifically assesses the ease of tool application—including data requirements, model setup, and integration of sector-specific policy data—and the robustness and accuracy of the resulting MI estimates, thereby providing practical guidance for policymakers and practitioners on implementing and reporting EE1st.

ENERGY EFFICIENCY FIRST PRINCIPLE

According to Germany's NECP, the EE1st principle—as now formally anchored in Article 3 of the EED—serves as the overarching guideline across all energy sectors (BMWK 2024; European Union 2023). Germany implements EE and the EED through the German Energy Efficiency Act (EnEfG), which sets binding national primary and final energy reduction targets. However, up to now it does not include a direct transposition of Art. 3 EED, which would oblige the federal government to systematically examine demand-side measures (including their MIs) before supply-side or infrastructure investments are undertaken. The EE1st principle is already partially reflected in some other national measures and legislation. For example, in energy infrastructure planning, the network development plan incorporates demand-side resources and efficiency measures, including electromobility, heat pumps, battery storage, and demand-side

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management in industry. The ongoing amendment to the Energy Industry Act (EnWG) further establishes a System Development Strategy that embeds the EE1st principle into coordinated scenario frameworks, ensuring consistent consideration of EE across all infrastructure planning processes (BMWK 2024). The German Buildings Energy Act (GEG), decided in September 2023 with effectiveness from January 2024, promotes efficient energy use alongside RE deployment, supported by federal funding programmes for efficient new and existing buildings (BMWSB 2023). The Heat Planning Act (WPG), requires systematic heat planning, mandatory estimation of energy savings potentials, and identification of areas with high energy-saving potential.[1]

While several EE policy evaluations quantify a range of MIs beyond energy and emissions reductions, these typically cover specific sectors, time horizons and impact categories, so that MIs are captured in a fragmented way rather than through a single integrated quantification that would enable a uniform approach and comparison between different measures. While some impacts are captured in addition to energy and emission reductions, such as macroeconomic effects on additional employment due to EE projects (BMWK 2023), other impacts such as health and comfort benefits, reduced air pollutants, and impacts on energy poverty are often only assessed through studies and not integrated into official monitoring processes (BPIE 2024; terSteege and Vogel 2021). In the evaluations assessed for these case studies, indicators for additional employment, and distribution by region or socio-economic status are also documented (Heinrich et al. 2025a; Heinrich et al. 2025b; Neusel et al. 2024; Rao et al. 2024).

CASE STUDIES: ENERGY EFFICIENCY PROGRAMMES

Three case studies were selected on the basis of sectoral representativeness, data availability, and policy relevance: the Federal Funding for Efficient Buildings (BEG) for the residential sector, the Environmental Bonus for the transport sector, and the Federal Funding for Energy and Resource Efficiency in Industry (EEW) for the industrial sector. All three programmes have been subject to rigorous, publicly available evaluations, providing robust input data for the MICATool and transferable methodological insights for reporting on and assessing EE1st implementation.

Federal funding program for energy efficient buildings (BEG)

The BEG is a fiscal instrument introduced by the Federal Ministry for Economic Affairs and Climate Action (BMWK, now Federal Ministry for Economic Affairs and Energy (BMWE)) in 2021 to advance energy and climate protection objectives while simultaneously supporting the construction sector (BAFA 2026a). The programme consolidates previously separate funding mechanisms for EE and RE in the building sector, structured into four subprogrammes targeting different building types, occupants, and measures, and covering a broad range of interventions covering renovation and heating-related measures. The programme is documented in annual evaluation reports showing that private households receive represent 95% of all funding recipients, with owner-occupiers and landlords a smaller share, which has implications for the extent to which lower-income households benefit from the scheme (Heinrich et al. 2023b; Heinrich et al. 2023a, 2024a, 2024b; Heinrich et al. 2025a; Heinrich et al. 2025b). This case study focuses specifically on the residential buildings component, examining two improvement actions applied to existing buildings: measures for building envelope insulation (Improvement Action 1) and heating system interventions including installation, optimisation, and combined approaches (Improvement Action 2).

The directive to promote the sale of electric-powered vehicles (environmental bonus)

The Environmental Bonus ("Umweltbonus") was a fiscal instrument introduced by the German government in 2016 to promote the electrification and decarbonisation of road transport, serving both climate protection and industrial policy objectives in terms of supporting the manufacturing sector and industrial transformation (BAFA 2026c). The scheme provided financial subsidies to private households and companies purchasing or leasing electric vehicles, complemented by mandatory manufacturer discounts. Over its operational period from 2016 until its early termination in 2023—curtailed one year ahead of schedule due to federal budget constraints—the programme approved €10.2 billion in government funding (supplemented by €5.3 billion in manufacturer rebates), supporting the registration of approximately 2.2 million electric vehicles:

1 Changes in the political landscape mean changes in the implementation of legislation where from 2029 it is expected that the regulations for the types of technologies required for heating will be relaxed with future allowances for new gas heater installations allowed. From 2029, these will need to be refitted to allow for biofuel blending (BMWE 2026).

1.4 million battery electric vehicles (BEVs), 0.8 million plug-in hybrid electric vehicles (PHEVs), and nearly 500 hydrogen fuel cell vehicles (FCEVs). The funding guidelines underwent multiple revisions throughout the programme's duration, with BEVs and FCEVs consistently receiving higher subsidies (€2,000–€6,000) than PHEVs (€1,500–€4,500) to incentivise lower-emission vehicle adoption. PHEV subsidies were discontinued at the end of 2022, and from 2023, BEV support was restricted to private individuals only and vehicles priced above €65,000 were excluded entirely. The dissemination of electric vehicles supported through this programme contributed to net annual energy savings of 10,903 GWh in 2023, described in an evaluation report (Rao et al. 2024). This case study focuses on impacts resulting from the uptake of BEVs only.

Federal funding for energy and resource efficiency in industry (EEW)

The EEW is an ongoing fiscal instrument established in 2018 by consolidating various BMWK funding programmes, pursuing energy, climate protection, and economic policy objectives by supporting companies in industry and commerce with measures to reduce energy consumption, resource use, and greenhouse gas emissions (GHG) (BAFA 2026b). The programme operates through grants, loans, and a competitive tender scheme across six funding modules covering cross cutting measures such as process optimisation, waste heat recovery, electrification, and renewable heat, as well as sector specific investments in energy and resource efficient production processes, with funding rates ranging from 25% to 60% of eligible costs and additional bonuses for small and medium sized enterprises. Between the programme's implementation in 2019 and the end of 2023, approximately €2.9 billion in funding was approved (with €36.7 million in administrative costs), generating new gross final energy savings estimated at 1,900–4,260 GWh annually across the programme, as described in the evaluation report (Neusel et al. 2024). These modules were consolidated into three overarching improvement actions for cross-cutting technologies, fuel switching, and process-specific savings for the case study.

METHODS

This paper demonstrates how the MICATool can be applied to assess MIs using three EE programmes in Germany to support a simplification for Member States to implement the EE1st principles, meet reporting obligations and promote informed decision-making to achieve energy and climate objectives.

The underlying methodology of the publicly available open-source MICATool is grounded in a quantification and monetisation framework for MIs associated with the energy savings of EE improvements (MICAT 2026). This framework is being extended to incorporate RE sources (RES) and includes a large variety of environmental, economic and social MIs. The conceptual model establishes a systematic quantification pathway from input parameters to outputs, yielding quantified, monetised, and aggregated MI indicators which than can be used in a respective (societal) cost-benefit analysis (CBA). This methodological approach enables both ex-ante assessment of projected impacts under various scenarios and policy interventions across different governance levels, as well as ex-post evaluation of realised impacts based on user-provided empirical data. In addition, the tool/approach offers a wide range of (customisable) default data to keep data requirements low and suitability/flexibility for various use cases high. An extensive description of the methodology can be found in the online documentation of the MICATool, as well as in (Berger et al. 2025).

For the case studies described in this paper, a national ex-post analysis is carried out using data from the evaluation reports for each of the EE programmes as input data into the MICATool with little need for modification and included data for annual investments, annual energy savings, technology life time, subsidy quota, and—where applicable—the share of energy carriers affected through the implementation of the improvement actions or the number of households affected or the share of households experiencing energy poverty affected. Where data is not available, the tool contains default values that will enable an assessment nonetheless (Berger 2024). The input data as extracted from the evaluation reports described in the section detailing the case studies and used for each EE programme is provided in the supplementary material (see Table 8, Table 9 and Table 16). The tool calculates the MIs over the lifetime of the programme given within the online platform or downloadable as an Excel file. The results are converted to specific impacts (e.g. per Euro invested, per unit of energy saved) so as to make the results comparable across the programmes. These are presented in the following sections.

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RESULTS & DISCUSSION

The MICATool quantifies the social, economic and environmental impacts and the monetisation of various indicators as well as conducts a Cost-Benefit Analysis based on the MICAT methodology (Berger et al. 2025; SEED MICAT 2023). The scope varies across programmes: the BEG assessment covers the residential component only, the Environmental Bonus covers BEV uptake under the current electricity mix, and EEW results are reported either for Improvement Action 3a or for the full programme, depending on data availability in the underlying literature. A comparison under renewable electricity is provided in the supplementary material (see Table 10–Table 15). As with any modelling framework, the MICATool outputs are inherently constrained by model-specific assumptions and the quality of input data. These limitations may affect the reliability and precision of long-term projections and impact assessments, particularly in the context of evolving and complex energy system dynamics. For instance, the MICATool follows an indicator-based approach, which means it calculates impacts based on predefined activity indicators and emission/impact factors without explicitly representing feedback loops or systemic interactions (i.e., it operates under a marginality assumption). Consequently, secondary effects such as price responses, demand re-adjustments, or induced technological change are not captured. While default parameter values are provided for ease-of-use, they rely on simplifying assumptions about energy mixes and sectoral dynamics, which may not fully reflect real-world complexities—especially in rapidly changing systems. Users can improve results accuracy by substituting default values with higher-quality, context-specific data where available.

SOCIAL IMPACTS

The quantification of social impacts centres around health impacts and the improvement of living standards and include reduction of air pollution to prevent premature deaths and mitigation of lost working days, alleviation of energy poverty, avoided asthma cases and reduction of cold-weather mortality. These indicators show which programme delivers the greatest social and health benefits (Table 1). In the BEG, building renovations and heater exchanges are expected to improve indoor climate, thereby reducing excess cold weather mortality and avoided asthma cases. In addition, lower air pollution (see section “Environmental impacts”) reduces associated health effects and work absences and improved energy poverty and productivity (BPIE 2024). In the MICATool, energy poverty indicators track how the measures improve energy affordability by lowering energy costs. Overall, the BEG programme results in positive social impacts while the other two programmes, Environmental bonus and EEW, do not target the residential sector, and do not have direct impacts on energy poverty and indoor climate. However, both programmes lead to a reduction in air pollution and thus have an impact on the associated mortality, and the number of hospital admissions and lost working days.

		BEG	ENVIRONMENTAL BONUS	EEW
		2021–2023	2016–2023	2019–2023
Avoided health effects linked to reduced air pollution				
Mortality	*Reduction in casualties (#)*	78	52	99
Hospital admissions		58	39	74
Avoided lost working days due to air pollution				
Avoided absences	*days*	27,010	18,892	35,048
Reduction in disability adjusted life years				
Avoided asthma cases	*years*	118	N/A*	N/A*
Estimated number of people lifted out of energy poverty				
Energy expenditure half the median (M/2)	*people*	214,737	N/A*	N/A*
Energy expenditure twice the median (2M)	*people*	297,790	N/A*	N/A*
Reduction in excess cold weather mortality				
Reduction in casualties	*Reduction in casualties (#)*	184	N/A*	N/A*

Table 1 Quantification of social impacts related to energy efficiency measures in Germany in the MICATool.

Status of data and SEED MICATool 03.03.2026.

**Note:* There are no values for the indicators for avoided asthma cases, energy poverty or the reduction in excess cold weather mortality for the Environmental bonus or EEW as the measures have no direct impact.

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To compare the results across the programmes, the specific impacts are calculated for some indicators. Figure 1 depicts the specific avoided health impacts linked to air pollution per unit of energy saved for each of the three EE programmes. The BEG and Environmental bonus show the greatest improvements largely due to the greater reduction in air pollutants.

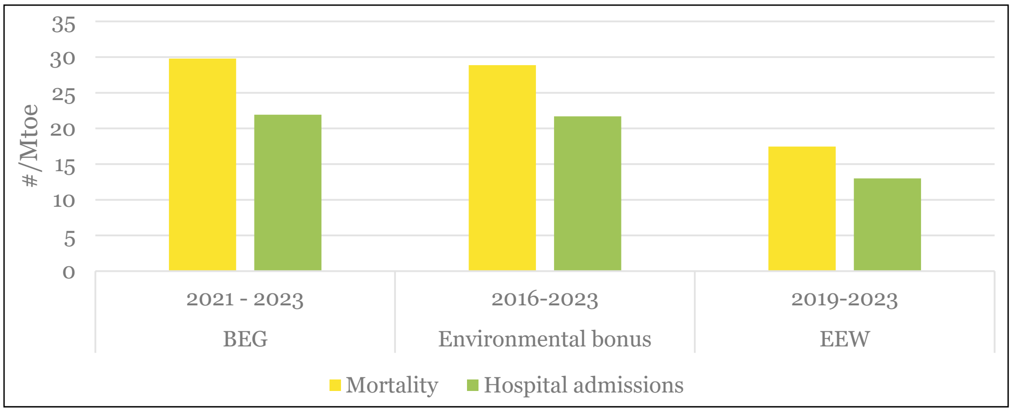

Figure 1 Specific avoided health impacts per unit of energy saved.

In 2022, Germany exhibited the third-highest attributable mortality in Europe from long-term exposure to $PM_{2.5}$ and NO_2, and the highest for O_3 with corresponding average years of life lost (YLL) per 100,000 inhabitants of 535 for $PM_{2.5}$, 155 for NO_2, and 231 for O_3 (EEA 2024). Over the duration of the programmes, the estimated reduction in years of life lost (YLL) per 100,000 inhabitants amounts to less than 1 for each of the programmes, but as these programmes address only a limited share of emission sources within individual sectors, the estimated reductions in years of life lost and air pollution related mortality are within the expected range. Direct validation remains difficult because comparable values are not reported in the literature or evaluation reports. The transport sector remains a major source of air pollution in Germany. The Environmental bonus BEV switches oil-based fuels to electricity resulting in significant reductions in CO_2 and NO_x, but lead to further SO_x pollutants emitted due to the additional electricity generation required, which would potentially decrease in the future as the electricity supply sector is continually decarbonised (see also Section "Environmental impacts" (Table 4) and the supplementary data for a comparison for this measure with a renewable electricity supply (see Table 12)).

ECONOMIC IMPACTS

The economic impacts comprise indicators related to the implementation of the EE programmes and capture the impact of EE measures on the energy system and the overall Gross Domestic Product (GDP) over the duration of the programmes, as shown in Table 2.

Table 2 Quantification of economic impacts related to energy efficiency programs evaluated in Germany in the MICATool.

Status of data and SEED MICATool 03.03.2026.

		BEG	ENVIRONMENTAL BONUS	EEW
		2021–2023	2016–2023	2019–2023
Energy impacts				
Energy intensity	*Change in ktoe/Mio. €*	–0.75	–0.89	–0.93
Import dependency	*%*	–0.002	0.006	–0.003
Reduction of additional generation capacity	*MW*	528	–18,198	3,524
Onshore wind	*MW*	152	–5,405	1,261
Offshore wind	*MW*	11	–388	91
Solar	*MW*	365	–12,405	2,173
Economics and employment				
Gross Domestic Product	*Added value (Mio. €)*	67,331	27,475	7,964
Additional employment	*Full-time employment years (years)*	1,122,018	410,678	129,431

The EE programmes reduce energy intensity and trigger investments, which in turn produces an added value to the GDP and macroeconomic effects such as increasing employment (Rajbhandari and Zhang 2018). The BEG programme exhibited the greatest reduction in energy and import dependency, while increasing GDP and additional employment. On average, the construction industry contributed about 4.9% to the total GDP in Germany between 2021 and 2023 (equating to a total of 523 billion EUR), of which the BEG contributes 13% (Destatis 2026). The EEW contributed considerably towards reducing the energy intensity while adding to the GDP, which is corroborated in high income countries such as Germany (Rajbhandari and Zhang 2018).

Figure 2 compares the GDP impacts per euro invested generated using the MICATool across the EE programmes. These results suggest that the BEG—primarily through construction activity—and the EEW—through industrial activity—exert the strongest effects on GDP growth. The specific impact on additional full-time employment years was also calculated with the MICATool and, as shown in Figure 3, exhibits less deviation across the programmes.

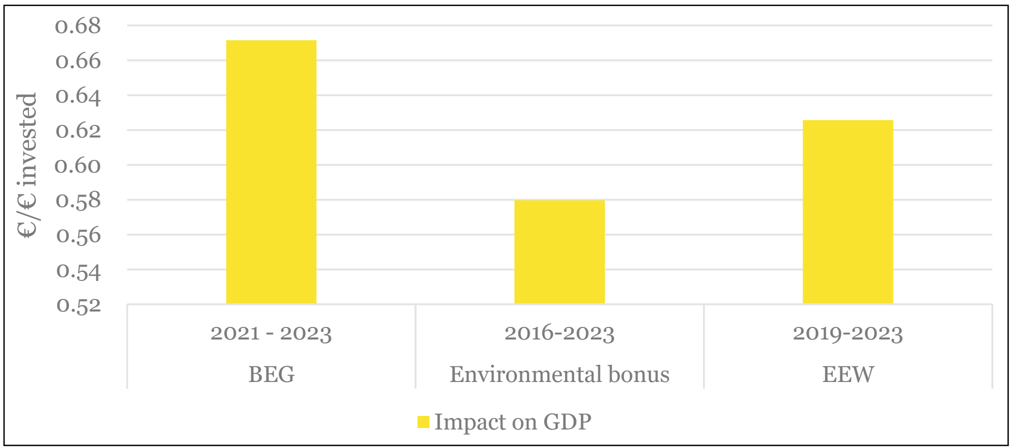

Figure 2 Specific impact on GDP per EUR invested by EE programme.

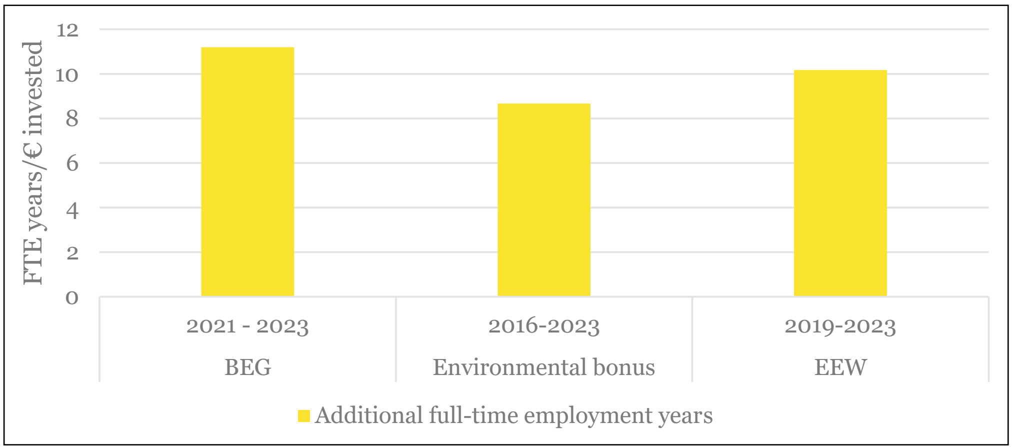

Figure 3 Specific impact on employment per million EUR invested by EE programme.

The evaluation reports on the EE programmes provided estimates of the annual macroeconomic impacts, e.g. on GDP and additional employment, which can be directly compared with the MICATool outputs, as shown in Table 3. For the BEG, MICATool estimates fall within the same order of magnitude as those reported in the evaluation report. In 2020, national assessments reported an estimated 393,000 full-time equivalent (FTE) years of additional employment and a GDP contribution of €79.1 billion, whereby these estimates cover both residential and non-residential renovations (BMWK 2023). This consistency between the MICATool results and the official estimates supports the validity of the tool's sector-specific impact assessments. The evaluation report for the environmental bonus did not report values on the additional employment as specific trends attributed to the programme could not be clearly identified although the markets share of BEV in the German market while the additional number of employees in this sector have grown in general, and a direct comparison for the national GDP contributions was not possible as these were given as contributions to the regional gross value added (GVA) (Rao et al. 2024). For the EEW, the report provides estimates for the contribution to the GDP and additional employment for the improvement action 3a for process-specific savings, which are within range with the outputs from the MICATool. National estimates estimate that EE investments in the industrial sector for manufacturing led to an additional 11,600 employees in 2020 (BMWK 2023), which is of comparative value with the outputs from the MICATool (in 2020 14,070 additional full-time employment years were added in EEW 3a).

Table 3 Comparison of values in the evaluation reports with values from the MICATool.

Status of data and SEED MICATool 03.03.2026 and comparison with (Heinrich et al. 2025b; Heinrich et al. 2025a; Rao et al. 2024; Neusel et al. 2024).

			BEG	ENVIRONMENTAL BONUS	EEW 3a
			2023	2023	2023
Energy impacts					
Gross Domestic Product	*Added annual value (Mio. €)*	MICATool	22,444	8,058	2,060
		Reports	22,640	N/A	1,200
Additional employment	*Full-time annual employment years (years)*	MICATool	374,006	120,438	33,437
		Reports	359,000	N/A	22,500

ENVIRONMENTAL IMPACTS

The quantification of the environmental impacts includes an overview of the impacts related to savings in primary energy, savings contribution to RE targets, and reduction in air pollution and GHG emissions over the lifetime of each programme as shown in Table 4 with the greatest reduction for the EEW, followed by BEG, while the Environmental bonus has a net positive decrease in the use of oil, but an increase in energy in the supply sector due to the fuel switch to electricity consumption (as seen by the negative values shown, which represent increased consumption of these specific fuels).

Table 4 Quantification of environmental impacts related to energy efficiency programs evaluated in Germany in the MICATool.

Status of data and SEED MICATool 03.03.2026.

		BEG	ENVIRONMENTAL BONUS	EEW
		2021–2023	2016–2023	2019–2023
Energy impacts				
Primary energy savings	*Total ktoe*	2,623	1,814	5,687
Oil	*ktoe*	643	5,416	395
Coal	*ktoe*	74	–1,441	692
Gas	*ktoe*	1,382	–840	3,840
Biomass and renewable waste	*ktoe*	459	–172	442
Renewables	*ktoe*	30	–778	92
Other	*ktoe*	35	–370	226
Change in RES targets	*%*	0.000	0.000	0.001
Emissions				
Reduction in air pollution	*kt*	7	26	15
SO_2	*kt*	1	–4	3
NO_x	*kt*	4	30	11
PM_2_5	*kt*	1	0	0
Reduction in GHG emissions (CO_2)	*kt*	6,455	8,423	12,974

In absolute terms, the scale of the overall reductions in primary energy and emissions in the EEW are doubled compared to the BEG over the lifetime of the EE programmes (Table 4). Comparing the specific impact of each programme, the BEG and EEW perform similarly for both CO_2 emissions (Figure 4) and air pollutants (Figure 5). The Environmental bonus has the greatest specific impact on net CO_2 emissions saved owing to the reduction in reliance of oil (Figure 4) and reduction in NO_x (Figure 5), but due to the increased electricity consumption leads to additional air pollutants (SO_x) related to additional electricity generation from other fuel sources including fossils (see also supplementary data for a comparison for this measure with a renewable electricity supply (see Table 14)). Whereas the EEW saves more energy consumption from coal, gas and district heating, the BEG saves more oil, which has a higher emission factor.

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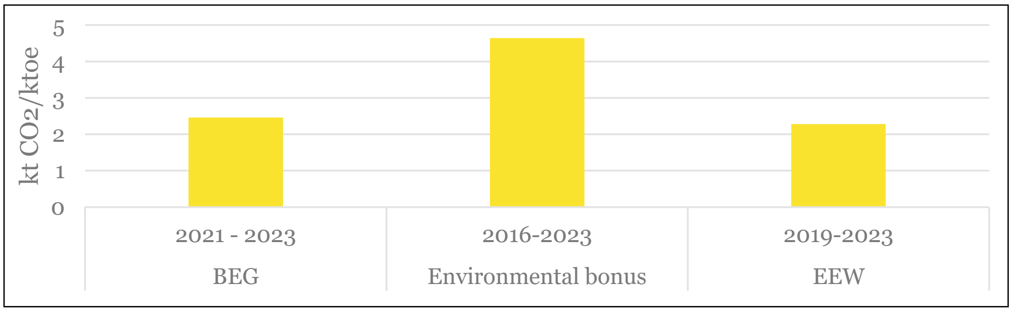

Figure 4 Specific impact on CO_2 emissions per unit of primary energy saved by EE programme.

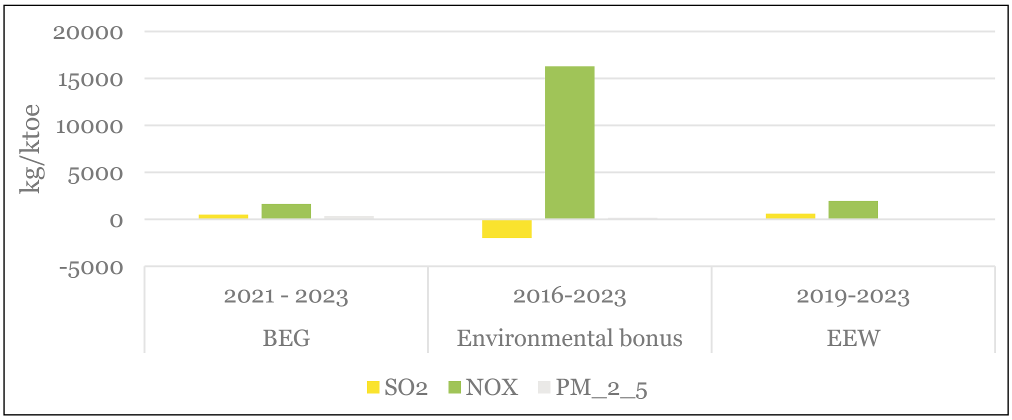

Figure 5 Specific impact on air pollution per unit of primary energy saved by EE programme.

The specific impact on the primary energy savings per unit of investment is shown in Figure 6, which shows that overall the EEW performs the best with 0.45 units of energy saved per unit of investment, followed by the Environmental bonus with 0.04 and BEG with 0.03.

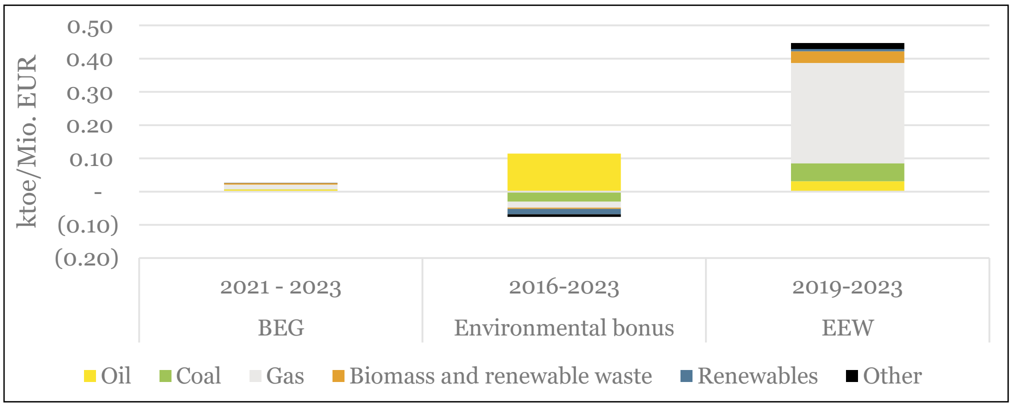

Figure 6 Specific impact on primary energy saved per million EUR invested by EE programme.

The evaluation reports provided estimates of the annual impact on primary energy savings and the reduction in GHG emissions (adjusted to reflect the consolidations of the programme to fit into the tool) which can be compared with the values produced by the MICATool, as shown in Table 5. While the values for BEG and the Environmental bonus are within range with each other, the values for EEW vary greatly due to the variation in the types of technologies and processes implemented and the simplification of these reflected as generalised processes in the tool. The observed variation in the estimated GHG emission reductions for the BEG arises from differences in the consolidation of inputs within the MICATool due to insufficient information regarding the affected fuels in the BEG and assumptions are therefore based on default values in the tool.

Table 5 Comparison of values in the evaluation reports with values from the MICATool.
Status of data and SEED MICATool 03.03.2026 and comparison with (Heinrich et al. 2025b; Heinrich et al. 2025a; Rao et al. 2024; Neusel et al. 2024).

			BEG	**ENVIRONMENTAL BONUS**	**EEW 3a**
			2023	**2023**	**2023**
Energy and emission impacts					
Primary energy savings	*Total ktoe*	MICATool	400	Oil: 628	411
		Reports	383	Oil: 601	238
Reduction in GHG emissions ($CO_{2\text{-eq}}$)	*kt*	MICATool	968	1,471	857
		Reports	1,511	1,617	1,262

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MONETISATION

Monetising indicators translates non-financial, qualitative, and environmental/social impacts into monetary terms. By establishing a single, comparable unit for a broad spectrum of often intangible effects, this approach supports more informed decision-making, enhances cost-benefit analyses, and enables externalities to be incorporated into business or policy assessments. However, not all indicators discussed above are monetised in the tool, e.g. because they are of a purely theoretical nature and do not generate a direct, measurable benefit, or because assigning a monetary value is either not feasible or not appropriate. This may be the case, for example, when no robust valuation approach is available or when monetisation would distort results through double counting. For example, the environmental indicator "reduction in air pollution" captures the avoided emissions of $PM_{2.5}$, NO_x and SO_2, but if these effects were also expressed in monetary terms, they would be double accounted as they are already reflected in the first two social indicators on air quality. Table 6 shows the results of the monetisation of the EE programmes over the analysed duration of the programmes given as undiscounted values. Across all programmes, monetised benefits are dominated by GDP effects, although their relative importance declines from the BEG to the Environmental Bonus and the EEW. By contrast, reductions in end user energy costs constitute the second largest benefit and become more prominent from the BEG to the Environmental Bonus and the EEW. It is important to note that some benefits, such as GDP, are once-off, while other benefits, such as energy savings, are accrued annually over the lifetime of the related savings. Therefore, analysing the MIs over their lifetime may alter the relative importance/size of the different indicators compared to the assessment of a dedicated timeframe for each measure (see also CBA analysis). Overall, compared to the investments made, the EEW generated the greatest multiple benefits owed largely to the energy cost and related emission reductions accrued.

		BEG	ENVIRONMENTAL BONUS	EEW
		2021–2023	2016–2023	2019–2023
Reduction of energy costs	*Total savings in Mio. €*	2,766	3,191	2,612
Reduction of GHG emissions	*Value in Mio. €*	1,197	1,962	561
Health effects linked to reduced air pollution	*Value in Mio. €*	205	208	198
Avoided asthma cases	*Value in Mio. €*	11	N/A	N/A
Avoided excess cold winter mortality	*Value in Mio. €*	470	N/A	N/A
Avoided lost working days due to air pollution	*Value in Mio. €*	3	4	7
Impact on RES targets	*Value in Mio. €*	58	39	120
Impact on gross domestic product	*Value in Mio. €*	67,331	27,475	7,964
Total multiple benefits generated per million EUR invested	*Mio. €/Mio. €*	0.72	0.69	0.9

Table 6 Monetisation of the multiple impacts related to energy efficiency programs evaluated in Germany (2016–2023) in the MICATool.

Status of data and SEED MICATool 03.03.2026.

Figure 7 compares the total investment and monetised benefits across the three programmes. The benefits over the lifetime of the measures are assessed in the Cost-Benefit Analysis (CBA) in the following section.

COST-BENEFIT ANALYSIS

The cost-benefit analysis (CBA) provides information about the annuity, net present value (NPV), levelised costs of energy savings (LCOE) and levelised costs of carbon dioxide (LCOCO2), cost-benefit ratio and benefit-cost ratio over the lifetime of the implemented EE measures or programmes.[2] The weighted annuity is the annuatised value of a project's costs and benefits expressed as yearly payments over its lifetime. A positive annuity

2 The CBA assessment includes the indicators for reduction of energy costs, reduction of GHG emissions, health effects, asthma cases, cold winter mortality, avoided lost working days, impact on RES and are calculated by default with a discount rate of 3%.

indicates that annual benefits exceed costs, signalling financial viability, while a negative value indicates the opposite. Similarly, a positive NPV indicates the projected earnings exceed costs, whereas a negative NPV reflects net costs over the project lifetime. As illustrated in Figure 7, the inclusion of macroeconomic effects, such as the impacts on GDP, has the strongest influence on the financial performance of the EE programmes. Beyond improving EE, these programmes were intended to also stimulate economic activity, which is reflected in GDP-related indicators.

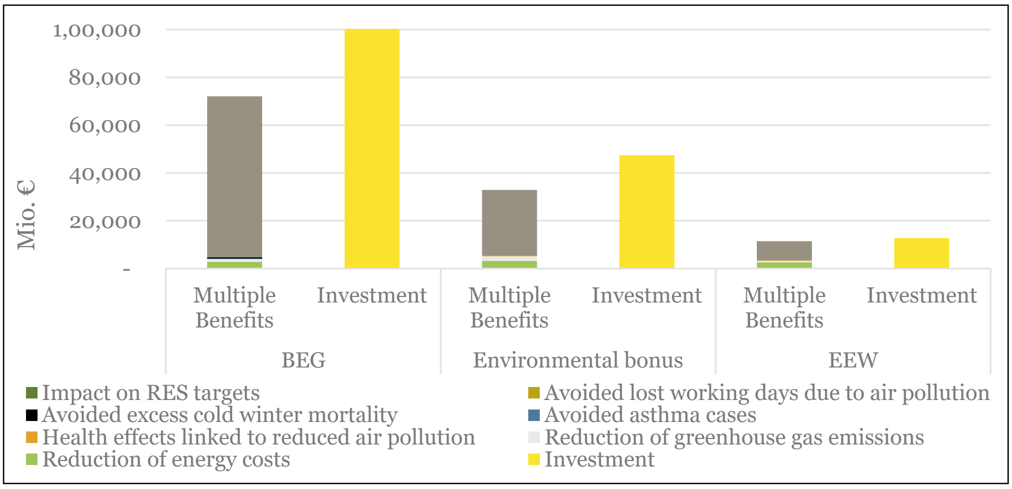

Figure 7 Monetisation of key indicators and comparison of total investment and multiple benefits by EE programme.

To isolate the contribution of different MI components, the CBA is first assessed considering energy cost reductions only. Under this perspective, financial performance varies substantially across programmes, reflecting differences in their nature and cost structures. When only energy cost reductions are considered, investment costs outweigh cash inflows, resulting in negative financial viability across all programmes. Correspondingly, the LCOE and $LCOCO_2$ values are comparatively high, driven by the high upfront investment costs relative to the energy and CO_2 savings achieved.

When monetised multiple impacts are included in the assessment (while still excluding the impact of GDP) the improvement in the financial viability of the programmes become visible. The LCOE represents the average cost per Megawatt-hour of energy produced or saved over a project's lifetime and serves as a benchmark for comparing technologies. Within the MICATool framework, this indicator additionally incorporates monetised multiple impacts, which can outweigh costs and result in negative LCOE values. These values are averaged over the programme duration and weighted by each year's new annual savings. Under this broader assessment, the financial viability of the BEG and EEW 3a programmes becomes positive, while the Environmental bonus shows a substantial improvement. The same trends are observed for both LCOE and $LCOCO_2$.

The performance of the Environmental bonus programme is strongly influenced by assumptions regarding the electricity supply sector, which in the default MICATool settings is not fully decarbonised in order to reflect current conditions. Assuming a fully decarbonised electricity sector leads to a marked improvement in performance in which financial viability increases significantly, while LCOE and $LCOCO_2$ decline substantially, decreasing by 54% and 75%, respectively thereby representing lower costs to save energy and reduce emissions (see Table 11 in the supplementary data).

When the economic benefits associated with GDP effects are included, all EE programmes become financially viable, as was illustrated in Figure 7. Under this comprehensive assessment, both LCOE and $LCOCO_2$ decrease sharply across all programmes. This result highlights how the perceived performance of EE programmes shifts when a broader set of MIs is considered, particularly given that stimulating economic activity was an explicit objective of these programmes alongside EE improvements. A comparison of the differences between considering the reduction in energy costs and including all MIs without impact of GDP is shown in Figure 8 and additional results are shown in Table 17–Table 19 in the supplementary data.

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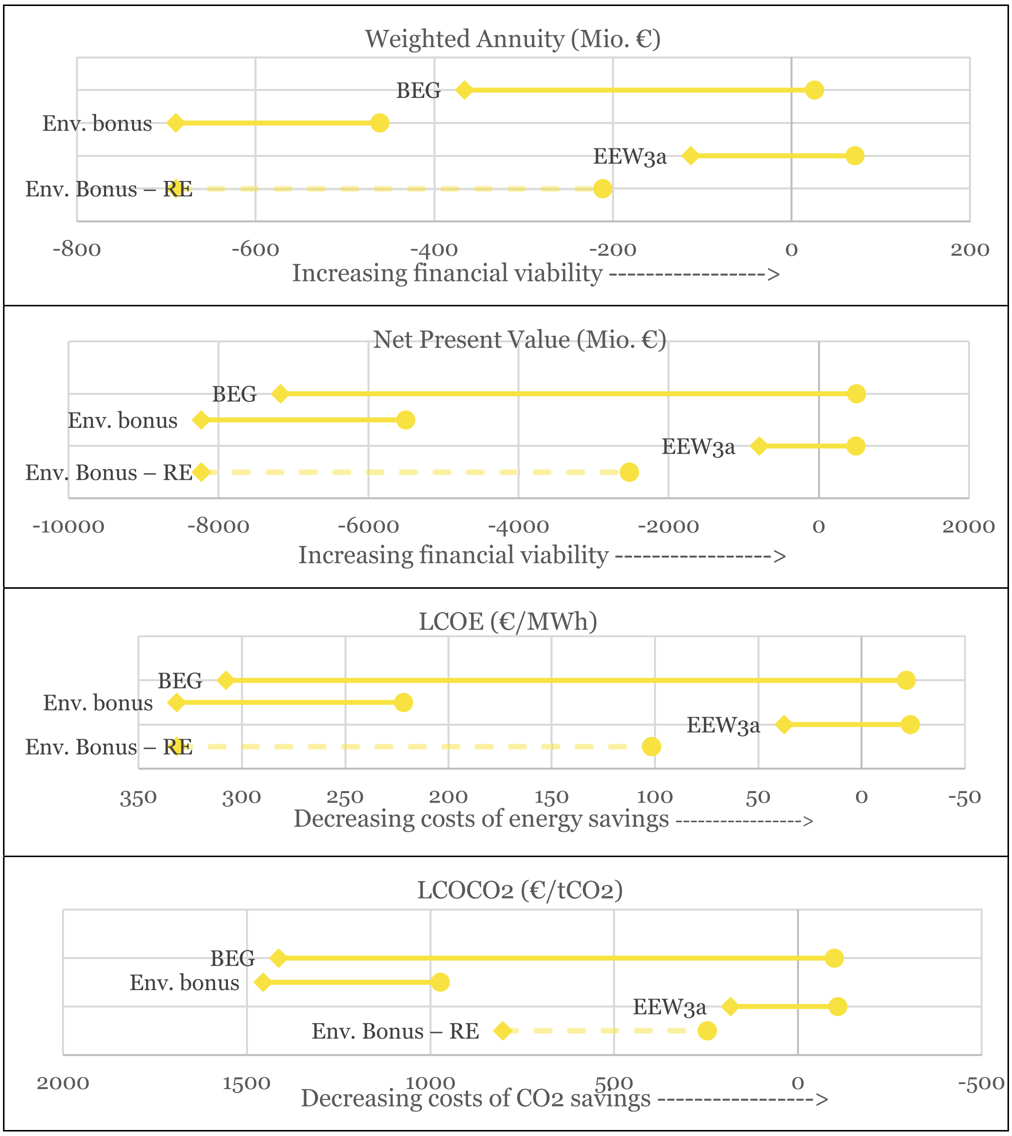

Figure 8 Comparison of cost benefit indicators for EE programmes (BEG, Environmental bonus, EEW3a, Environmental bonus—RE). The values show the difference between considering the benefit of the reduction in energy costs only (left points) with the inclusion of all MIs without the impact of GDP (right points). Status of data and SEED MICATool 03.03.2026.

COMPARATIVE ASSESSMENT OF RE vs. EE

Energy planning involves deciding between investing in new RE capacity to meet demand and prioritising EE measures that lower final energy demand and thus reduce the need for additional generation capacity. The MICATool enables the quantitative assessment of RE impacts and their systematic comparison with EE impacts, thereby supporting an empirical evaluation of the EE1st principle. This comparison was undertaken by comparing the impact of EE through residential building envelope renovations (improvement action 1) under the BEG programme with investments in renewable electricity supply through rooftop photovoltaic (PV) systems, in which fundamental differences in their impacts on the system are highlighted. While PV investments primarily aim to meet existing electricity demand with low carbon-supply (the assumption for the calculations were that the PV produces the amount of electricity saved through the EE measures for building envelope renovations), BEG renovations directly reduce final energy consumption through efficiency improvements.[3] A comparison of a sample of monetisation results generated over the lifetime of the programme (2021–2023) for both examples is provided in Table 7.

Comparing the different investment approaches (EE vs. RE) can yield different benefits. While investing in RE with rooftop PV contributes to emissions reductions, reducing health effects linked to reduced air pollution and associated lost working days, achieving RE targets and stimulates the economy, renovation activities as in the BEG generate higher macroeconomic benefits, reflected in a stronger positive impact on GDP, due to their labour-intensive nature and domestic value chains. Renovations also achieve a broader variety of MIs, such as avoided

3 Installed capacity for rooftop PV used in the tool for the comparison: 2021: 650 MW, 2022: 2,380 MW, 2023: 3,704 MW.

cold winter mortality and have (in this case) a higher impact on reducing emissions. Assessing the benefits of each approach in parallel enables a fair comparison across measures and provides a basis for selecting the solution, or combination of solutions, that delivers the most favourable overall balance with respect to the pursued policy objectives thereby illustrating the best practice in operationalising the EE1st principle in the residential sector.

		BEG, RENOVATIONS ONLY	ROOFTOP PV*
Reduction of GHG emissions	*Mio. €*	260.0	177.2
Health effects linked to reduced air pollution	*Mio. €*	45.1	37.4
Avoided asthma cases	*Mio. €*	6.2	N/A
Avoided excess cold winter mortality	*Mio. €*	282.4	N/A
Avoided lost working days due to air pollution	*Mio. €*	0.7	0.6
Impact on RES targets	*Mio. €*	12.7	30.8
Impact on gross domestic product	*Mio. €*	33,528.6	1393.2
Total multiple benefits generated	*Mio. €*	34,743.03	1,639.24
Multiple benefits generated per EUR invested	€/€	0.72	0.43

Table 7 Monetisation of multiple impacts related to the installation of rooftop PV instead of implementing energy efficiency in buildings through the BEG envelope renovations (aggregated over 2021–2023).

*Not all features are yet fully available in the renewable energy module of the MICATool.

CONCLUSIONS

To demonstrate how the wider benefits of EE can be systematically quantified to support the implementation of the EE1st principle, this paper shows that applying a harmonised multiple-impacts framework fundamentally changes how energy policy options can be assessed and compared. Using three major German EE programmes across the residential, transport and industrial sectors, the results highlight that EE delivers substantial social, economic and environmental benefits well beyond energy and emissions savings alone. In particular, the analysis reveals strong contributions to adverse health impacts, reductions in energy poverty, improvements in energy security, and significant macroeconomic effects on GDP and employment—impacts that are largely invisible in conventional, assessments focussed only on energy and emissions savings. When these multiple impacts are monetised and incorporated into cost-benefit analyses, EE measures frequently outperform supply-side alternatives, underscoring their strategic relevance for infrastructure planning and investment decisions. By operationalising EE1st through a transparent and comparatively low-data-intensity approach, the MICATool demonstrates how Member States can move from a narrow, short-term perspective towards a more comprehensive societal evaluation of policies, thereby supporting more informed decision-making and more robust reporting under Article 3 of the revised EED.

ADDITIONAL FILES

The additional files for this article can be found as follows:

- **Supplementary Data.** Fact sheets on EE programmes and input data to the MICATool: BEG. DOI: https://doi.org/10.66506/essp.4-178-26.s1
- **PowerPoint Slides.** PowerPoint Slides relating to this article. DOI: https://doi.org/10.66506/essp.4-178-26.s2

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COMPETING INTERESTS

The authors have no competing interests to declare.

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