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# USING A DIGITAL TWIN ARCHITECTURE FOR MINIMUM WAGE DETERMINATION: THE MWDT FRAMEWORK FOR TÜRKİYE

## *Asgari Ücretin Belirlenmesinde Dijital İkiz Mimarisi Kullanımı: Türkiye İçin MWDT Çerçevesi*

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**ABSTRACT**

This study treats minimum wage setting in Türkiye not as choosing a single raise rate but as a multi-criteria decision problem with trade-offs across worker welfare, poverty risk, wage distribution, employer costs, informality, prices and public finances. Fragmented data, the gross-to-net translation shaped by tax–contribution–transfer rules, and uncertainty about employment and price pass-through weaken the evidence chain. Building on ISO/IEC 30173, the paper proposes a Minimum Wage Digital Twin (MWDT) as a modular decision-support architecture rather than an automated decision engine. A digital-thread data layer harmonizes wage/employment indicators, cost-of-living measures and policy rules, producing versioned snapshots for each decision cycle. In the model layer, M1 computes gross-to-net and budget impacts via microsimulation; M2 runs sector/region vulnerability and employment stress tests; M3 maps cost shocks to prices and living-cost baskets; and M4 generates distributional and adequacy KPIs. The scenario layer versions alternative wage levels, indexation rules and coverage assumptions under a common snapshot and rule set, enabling consistent KPI-basket comparisons. The objective is to enhance transparency and strengthen the institutional learning cycle within the Turkish context by initially piloting at the digital shadow level (characterized by one-way data flow from physical to digital), and then, through bidirectional feedback of post-decision inflation, compliance, and employment signals updating the rule sets and parameter bands, converging toward a digital twin. A governance/reporting layer records audit trails and model/parameter versions and packages outputs for stakeholders and experts. Developed through a design-science lens, MWDT supports phased piloting at a "digital shadow" level and calibration using post-decision outcomes, strengthening transparency, reproducibility and institutional learning.

**Keywords:** Minimum wage, digital twin, microsimulation, multi-criteria decision making

**ÖZ**

Bu çalışma, Türkiye'de asgari ücret tespitini tek bir artış oranının belirlenmesi olarak değil; refah, ücret dağılımı, işveren maliyeti, kayıt dışılık, fiyat düzeyi ve kamu mali dengeleri arasında ödünleşimler üreten çok ölçütlü bir karar problemi olarak ele almaktadır. Süreçte veri altyapısının parçalı olması, brüt artışın net gelire dönüşümünde vergi–prim–transfer etkileşimleri ve istihdam/fiyat kanallarındaki belirsizlikler kararın kanıt zincirini zayıflatmaktadır. Makale, ISO/IEC 30173'ün dijital ikiz kavramsallaştırmasını politika alanına uyarlayarak Asgari Ücret Dijital İkizi (MWDT) adı verilen modüler bir karar-destek mimarisi önermektedir. MWDT, her karar döneminde sürümlenebilir veri anlık görüntüsü (snapshot) üreten bir dijital iz (digital thread) katmanı üzerine kuruludur. Model katmanında mikrosimülasyon temelli M1 (brüt-net ve bütçe etkisi), sektörel kırılganlık/istihdam stres testi M2, fiyat-geçinme kanalı M3 ve dağılım-yeterlilik modülü M4 birlikte çalıştırılarak KPI sepetleri üretilmektedir. Senaryo katmanı, alternatif ücret düzeyi/kuralı/kapsam seçeneklerini aynı veri ve kural seti altında koşup karşılaştırmakta; yönetişim katmanı ise audit trail, sürüm kayıtları ve paydaş odaklı rapor paketleriyle tekrar üretilebilirliği güvence altına almaktadır. Öneri, dijital gölge düzeyinde pilotlanıp, karar sonrası gerçekleşmelerle kalibrasyon eklenerek dijital ikize yakınsayan bir kurumsal "senaryo laboratuvarı" üretmektedir. Tasarım bilimi yaklaşımıyla geliştirilen artefakt, mevzuat-kriter eşlemesini görünür kılmakta; birinci tur (mikrosimülasyon) ve ikinci tur (istihdam/fiyat) kanallarını ayrıştırırak ve duyarlılık bantlarıyla belirsizliği standart biçimde raporlayarak ve kurumsal öğrenmeyi desteklemektedir.

**Anahtar Kelimeler:** Asgari ücret, dijital ikiz, mikrosimülasyon, çok ölçütlü karar verme

## INTRODUCTION

The minimum wage is not merely an economic parameter that sets the lower bound of wage distribution. It is a multidimensional policy tool that simultaneously generates effects on worker welfare, poverty risk, wage hierarchy, firms' cost structures, informality, price levels, and public fiscal balances. Therefore, minimum wage setting should not be approached as a single-objective optimization problem but as a multi-criteria decision-making problem involving trade-offs between different objectives (Dube, 2019).

In Türkiye, the institutional framework for the minimum wage was defined by the "Minimum Wage Regulation" enacted in 2004. The regulation defines the minimum wage as "the wage paid to workers for a normal working day, which is sufficient to meet, at a minimum level, the worker's basic needs such as food, housing, clothing, health, transportation, and culture, based on prevailing prices" (Minimum Wage Regulation, 2004: Art. 4/d). It also stipulates that the country's social and economic conditions, cost-of-living indices, the general state of wages actually paid, and living conditions shall be taken into account during the determination process (Republic of Türkiye Ministry of Labour and Social Security [ÇSGB], 2004). This framework indicates that the decision should be viewed not merely as a matter of "bargaining" but also as a process justified by indicators and evidence.

International normative frameworks support similar logic. The ILO's Minimum Wage Fixing Convention (No. 131) emphasizes that the needs of workers and their families, along with economic factors, should be considered in setting minimum wages, alongside consultation with worker and employer representatives (ILO, 1970). At the European Union level, the "adequate minimum wage" approach has been institutionalized by linking minimum wages to criteria such as purchasing power, poverty risk, and their position in the wage distribution (European Parliament and Council of the European Union, 2022). Thus, both national and international frameworks require that minimum wage decisions be handled in a multi-criteria and evidence-based manner.

Nevertheless, in practice, three main challenges arise in minimum wage setting: First, the data infrastructure upon which the decision is based is often dispersed across different sources (similarly in Türkiye and many other countries): wage/employment indicators can be split between administrative records and surveys; informality, coverage differences, and definition-period inconsistencies challenge data integrity. Applications that simulate minimum wage scenarios using both survey and administrative tax data show that differences in the scope and measurement of data sources directly affect outcomes (Robayo-Abril, 2024). Second, a single "gross increase" may not yield the same "net/disposable income increase" for different household types; tax and social security contribution burdens, and interactions with transfer benefits, can dampen the net effect and, in some cases, create compound effects that may even reduce net income. EUROMOD-based simulations indicate that particularly for low-income groups, the net effect can be "cushioned" by tax/transfer mechanisms, and scenarios where net income decreases can occur (Grünberger et al., 2022; Maier & Ricci, 2022). Third, second-round (general equilibrium/behavioral) effects, such as impacts on employment and prices, are uncertain. Therefore, designing the decision process not around a single number but around a clearly defined scenario space with explicit assumptions and sensitivity bands is a more defensible method. While models like EUROMOD are strong at measuring first-round "static" effects, it is explicitly noted that they often treat macro/behavioral reactions—such as labor supply-demand responses and price adjustments—as external assumptions; this makes it methodologically meaningful to report second-round uncertainty through scenario bands (Grünberger et al., 2022).

To address these challenges, this study treats minimum wage setting as a "socio-economic system" and proposes representing this system with a digital twin architecture. The ISO/IEC 30173:2023 standard presents the digital twin as a framework describing concepts, terminology, lifecycle processes, stakeholders, and functional views, facilitating communication among different stakeholders (ISO/IEC, 2023; Spiryagin et al., 2025). From this perspective, the "target entity" (physical asset) is not limited to engineering systems; in the context of the minimum wage, the target entity is the policy system comprising wage-price-household welfare-tax/transfer-employment relationships. The distinctive aspect of the digital twin approach is that it establishes a representation (digital thread) updated via data connections while, on the other hand, enabling the comparison of the effects of alternative policy options within the same framework through scenario/simulation capabilities (ISO/IEC, 2023).

Digital twin literature discusses the integration levels of the concept with distinctions such as "digital model–digital shadow–digital twin," where the key difference lies in the direction and continuity of data flow between the physical and digital systems (Kritzinger et al., 2018). The aim of the proposed framework for the minimum wage is not to "twin the entire economy in real-time." The goal is to transform the data domains and decision criteria indicated in the legislation into a policy experimentation laboratory operating with versioned datasets and explicit assumptions: Alternative minimum wage levels/rules evaluated by the Commission are run in the same data-model ecosystem; results are reported with welfare, distribution, budget, and cost indicators; assumptions and the production chain of outputs (audit trail) are archived.

This approach is compatible with existing policy evaluation tools. For instance, in the European Union, EUROMOD-based microsimulation studies are used to measure the first-round distributional and fiscal effects of hypothetical minimum wage scenarios (Grünberger et al., 2021; Sutherland & Figari, 2013). The OECD's TaxBEN framework offers a family of models that transparently demonstrate gross-net conversion and tax-transfer composition using a "hypothetical household/vignette" approach (OECD, 2022). This study's contribution to literature is to integrate such tools not merely at the level of individual analyses but to embed them within an institutional architecture based on digital twin principles. This will make data updating, model versioning, assumption management, scenario archiving, and stakeholder reporting part of a single design.

In this context, the study's objective is to propose a modular decision-support architecture for minimum wage setting in Türkiye, which we call the Minimum Wage Digital Twin (MWDT). The MWDT is not an algorithm that "automatically delivers" the final decision. Instead, it is an analytical infrastructure that makes the multidimensional impacts of the decision visible and renders the trade-offs between different objectives comparable. Each criterion defined in the regulation is linked to a data domain in the architecture and a set of indicators in the output, thereby establishing a "legislation → data → model → report" pipeline.

This study's original contributions can be summarized in three points:

- It adapts the digital twin principles aligned with ISO/IEC 30173 to minimum wage policy, offering an architectural artifact focused on traceability (digital thread) and auditability (audit trail).
- It establishes a "criterion → data → module → output" mapping (Table 1) that translates the criteria set out in the Turkish Minimum Wage Regulation (Article 7), ILO Convention 131, and EU Directive 2022/2041 into baskets of KPIs.
- It proposes a "scenario laboratory" protocol that integrates microsimulation (M1), sectoral stress testing (M2), price/livelihood channel analysis (M3), and distribution/adequacy assessment (M4) with uncertainty reporting, thereby disentangling first- and second-round effects.

These original contributions will demonstrate how a traceable and auditable policy-support architecture can be designed and through which modular analytical steps a minimum wage decision can be generated.

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## CONCEPTUAL FRAMEWORK

In Türkiye, minimum wage determination is not merely a decision that sets the wage level; it is an institutional process encompassing dimensions of scope, method, and legitimacy. The Minimum Wage Regulation clearly sets out both the definition of the minimum wage and the evaluation axes of the Minimum Wage Determination Commission (Minimum Wage Regulation, 2004). Building upon this framework, this study defines the Minimum Wage Digital Twin (MWDT) approach as a socio-technical digital twin architecture that represents the core components of the minimum wage setting process (adequacy/living standard, position in wage distribution, compliance–employment dynamics, gross-to-net conversion, and fiscal effects) in modular form, synchronizes with real data/rule updates, and tests alternative policy scenarios in a traceable manner. Therefore, the MWDT is not merely a dashboard; it is a decision infrastructure that establishes the mapping (twin mapping) between data–model–rule sets, records assumptions, and produces an auditable trail for each scenario/decision.

The regulation's definition of the minimum wage as "sufficient to meet the basic needs of workers at a minimum level based on prevailing prices" creates a direct "adequacy anchor" from a digital twin perspective: the adequacy target, linked to a basket of basic needs and "prevailing prices," can be operationalized in the MWDT's cost-of-living module (Minimum Wage Regulation, 2004; Bhorat et al., 2014). Similarly, the explicit enumeration in the regulation of the information domains to be considered by the Commission in its decision-making (the country's social and economic conditions, cost-of-living indices/living conditions, the general state of wages actually paid, etc.) allows the definition of the MWDT's input domains based on legislation (Minimum Wage Regulation, 2004). Consequently, the first design principle for constructing the MWDT architecture is formulated as follows: Each criterion listed in the regulation must be linked to at least one measurable indicator (KPI) and an explicit data source.

International normative frameworks reinforce this multi-criteria logic. ILO Convention No. 131 emphasizes the consideration of both the needs of workers and their families and economic factors in minimum wage setting, as well as consultation with social partners (ILO, 1970). The European Union's Directive 2022/2041 institutionalizes the "adequate minimum wage" approach through both adequacy criteria and regular updates with social partner involvement; by referencing commonly used benchmarks (e.g., "reference values" such as minimum wage to median/average wage ratios), it aims to make adequacy assessment measurable (Grünberger et al., 2021). Reading these two frameworks together reveals two main evaluation axes for the MWDT: (i) adequacy/living standard, and (ii) economic sustainability–compliance (including employment and cost channels).

In light of these explanations, the objective in the MWDT architecture is to design the target criteria not as a single index but as sets of KPIs:

***(A) Adequacy and cost-of-living basket (Cost-of-living sub-twin).*** The capacity of the minimum wage to meet basic needs is monitored through real wage and basket coverage ratios. This basket provides an answer from a welfare perspective to the question, "Is a minimum wage increase necessary?" (Minimum Wage Regulation, 2004).

***(B) Wage distribution and relative position basket (Wage distribution sub-twin).*** The core indicators of this basket are the minimum wage ratio to median/average wage, the low-wage share, and wage compression. The benchmarking logic of the EU Directive enhances the comparability of this basket at an international level (Grünberger et al., 2021).

***(C) Compliance/employment and informality basket (Compliance–market response sub-twin).*** The applicability of the minimum wage is monitored through sectoral/regional breakdowns of compliance risks, signals of shifts into informality, and short-term employment indicators. This basket translates the regulation's principle that "payment below the minimum wage is not permitted" into an analytical monitoring dimension (ILO, 2020; Bhorat et al., 2014).

***(D) Net income and public fiscal effects basket (Gross-to-net conversion and fiscal-impact sub-twin).*** Since the conversion of a gross wage increase into net income is determined by tax–contribution–transfer rules, the calculation logic of this basket is inherently based on microsimulation/vignettes. While the EUROMOD approach offers an established methodological reference for assessing the distributional and fiscal effects of alternative policy scenarios via microsimulation (Sutherland & Figari, 2013), the OECD TaxBEN framework provides a complementary approach that can transparently demonstrate the gross-to-net mechanism using a "hypothetical household (vignette)" logic even in contexts with limited access to microdata. For the MWDT, the critical task is to link the outputs produced by these two approaches to a consistent decision report using the "KPI basket" logic (Grünberger et al., 2021; OECD, 2022).

Moreover, the MWDT's effectiveness is determined not only by its technical accuracy but also by its governance capacity. Therefore, the architectural design must ensure that: (i) assumptions are standardized in a registry, (ii) data/model/rule sets are version-controlled, and (iii) an audit trail is produced for each scenario. This approach aligns with the emphasis on stakeholder communication and lifecycle processes in ISO/IEC 30173 (ISO/IEC, 2023).

## LITERATURE REVIEW

The concept of adequacy focuses on measuring the relationship between the minimum wage, the cost of living, and a socially acceptable standard of living. In the specific context of Türkiye, the emphasis on "prevailing prices" implies that adequacy can be operationalized through price levels and a needs basket (Minimum Wage Regulation, 2004). The international framework reinforces this approach; the ILO's Convention No. 131 supports it by stressing the joint consideration of "needs" and "economic factors," along with a consultation mechanism (ILO, 1970). The EU's Directive 2022/2041 further aims to make adequacy assessments measurable by linking them to the position within the wage distribution, thereby enabling reference to commonly used indicator benchmarks (e.g., median/average wage ratios) in practice (EU, 2022/2041; Selberg & Sjödin, 2024). This common thread establishes a literature foundation that strengthens a “basket of indicators” approach over a single metric. Additionally, the “living wage” approach offers a methodological reference for defining adequacy based on a basket (needs basket + household structure + local prices), providing a conceptual underpinning for the MWDT’s adequacy module (Anker & Anker, 2017; ILO, 2025).

Since the welfare dimension of the minimum wage materializes through net income in practice, tax-contribution-transfer rules decisively channel the decision’s effects. EUROMOD provides a standard framework for multi-country tax-benefit microsimulation; Sutherland and Figari (2013) discuss the model’s scope and validation approach, highlighting that microsimulation typically produces “first-round/arithmetic” effects without behavioral responses in most applications. Grünberger et al. (2021), building on this, use EUROMOD to report the social and fiscal impacts of hypothetical minimum wage increases across multiple indicators. The OECD TaxBEN approach offers a complementary strand that enhances policy communication by transparently illustrating the gross-to-net conversion using a vignette/hypothetical household logic, even in contexts with limited microdata (OECD, 2022). In the Turkish context, studies developing tax-benefit microsimulation using TR-SILC data indicate a viable infrastructure path for the «micro-core» component of the MWDT (Erol, 2022).

However, the minimum wage literature is not confined to adequacy and first-round distributional effects; the decision’s impacts through compliance, informality, and employment channels also constitute a critical area of debate. While findings on the employment effects of minimum wages can vary by country, period, and institutions, a robust empirical literature points to the need for jointly analyzing wage compression/redistribution in the low-wage segment and employment responses (Belman & Wolfson, 2014; Cengiz et al., 2018). Regarding the compliance/enforcement dimension, the literature underscores that the gap between legal intent and actual outcomes can be substantial, particularly in developing economies, necessitating the inclusion of informality and compliance indicators within a “monitoring basket” (Bhorat et al., 2014). For Türkiye, studies examining the interaction of minimum wages—following significant hikes such as in 2004 and 2016—with wage distribution, informality, and firm behavior provide a foundation for why the MWDT architecture incorporates modules not only for “net income” but also for compliance risk and firm exposure (Akgündüz et al., 2019; Acar et al., 2019; Gürcihan Yüncüler & Yüncüler, 2019).

Concerning second-round effects, the debate on pass-through to price levels forms a separate strand in the literature. Studies synthesizing the transmission of minimum wage increases to prices show that the effect can vary across sectors and market structures. This variability supports the argument that treating price/employment channels in the MWDT through sensitivity bands, rather than single-point estimates, offers a more robust analytical approach (Lemos, 2008).

The digital twin literature provides the technical vehicle for the MWDT’s claim of supporting an “institutional decision cycle.” ISO/IEC 30173 standardizes the terminology, lifecycle processes, and stakeholder dimensions of a digital twin. Kritzinger et al. (2018) classify integration levels—digital model, digital shadow, digital twin—based on the direction and continuity of data flow. Furthermore, compilations of digital twin applications in the public domain to support decision and policy-making—particularly in complex socio-technical systems like smart cities—demonstrate that the triad of "scenario space + stakeholder governance + decision support" is discussed not only in engineering but also in public decision-making processes (Temple et al., 2024; van Merteen & Smit, 2025).

In summary, the literature: (i) defines adequacy and benchmark indicators, (ii) measures first-round distributional and fiscal effects via microsimulation, (iii) points to the uncertainty of second-round effects through channels like compliance, employment, and prices, and (iv) provides a common language for process and stakeholder integration via the digital twin approach. The contribution of the MWDT lies in elevating these components from the scale of a "single study" and integrating them into a repeatable, version-controlled, and auditable decision-support architecture.

## DESIGN OF THE MWDT ARCHITECTURE

Proceeding from the study's motivation, it is more accurate to define the Minimum Wage Digital Twin (MWDT) addressed in this article not as a singular "model," but as a modular decision-support architecture composed of data–model–scenario–governance components. Within this framework, the MWDT's objective is to report the outcomes of alternative minimum wage levels evaluated by the Minimum Wage Determination Commission in a comparable and traceable manner using a multi-KPI basket, by running them on the same data version, the same rule set, and with explicit assumptions.

The proposed architecture is positioned not as a mechanism that "automatically determines" the decision, but as an analytical infrastructure that "justifies the decision and renders it auditable." This shifts the decision debate from a focus on a single rate of increase to one centered on criterion-based impact profiles and trade-offs.

The study advances using a design science research approach; its output is not a one-time analysis report but an architectural artefact encompassing (i) a layered architecture design, (ii) inter-module data flows, (iii) a scenario protocol, and (iv) validation–reporting principles. The artefact's value is assessed along the dimensions of internal consistency, reproducibility, explainability (traceability/audit trail), and decision utility (Peffers et al., 2007; Gregor & Hevner, 2013; Ziemann et al., 2023).

Four key criteria guide the design process:

**(i) Regulatory Traceability:** Every data domain and output indicator must be traceable back to the provision of the Minimum Wage Regulation (Article 7) that defines the elements the Commission must consider (Minimum Wage Regulation, 2004).

**(ii) Modularity:** Channels for welfare (micro), sectoral/regional vulnerability–employment (stress test), and price pass-through must be structured as separate modules; the scenario engine must integrate these modules within a single run.

**(iii) Uncertainty-Band Reporting:** Particularly for employment and price effects, reporting should employ sensitivity bands and scenario comparisons instead of single-point estimates (Saltelli et al., 2004; EU, 2023).

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**(iv) Auditability (Audit Trail):** Data versions, parameters, assumptions, and scenario runs must be recorded in a version-controlled manner (Ziemann et al., 2023).

To render these criteria concrete, Table 1 below is provided, illustrating the MWDT's "legislation → data → model → report" pipeline. The mapping in Table 1 will serve as a reference framework for understanding which criteria are carried by which modules in the layered architecture (Figure 1) and for identifying which KPI baskets are produced within the scenario protocol (Figure 2).

**Table 1. Regulatory criteria → data domain → MWDT module → example KPIs.**

| Regulatory criterion (Article 7) | Data counterpart (example) | MWDT module | Example output (KPI) |
|---|---|---|---|
| Country's social and economic conditions | Unemployment/employment, growth, sectoral contraction indicators | M2 (Sectoral stress test) | Sectoral employment pressure index (with uncertainty bands) |
| Cost-of-living indices for wage earners | CPI sub-components + essential-needs basket index | M1 (Microsimulation) + M3 (Price channel) | Essential basket coverage ratio; real purchasing power |
| General status of wages actually being paid | Wage distribution (p10–p50), formal vs. informal wages | M1 + M4 (Distribution/adequacy) | Share of affected workers; wage compression indicator |
| Living conditions | Household-type-based expenditure/income structure | M1 (Microsimulation) | Change in poverty risk; net income increase |

The "criterion → data domain → MWDT module → indicator (KPI)" mapping established in Table 1 functions as a **traceability matrix**, specifying—at an operational level—which institutional criterion is translated into measurable outputs, based on which data inputs and through which computational components of MWDT. The transformation chain defined in this matrix is implemented through four architectural layers and the coordinated operation of modules M1–M4 within the model layer.

Accordingly, the **data layer (digital thread)** standardizes the data counterparts listed in Table 1 (wage/employment and wage-distribution indicators, price indices and essential-needs basket components, tax–contribution–transfer rule sets, and sectoral/regional context variables) within a single decision data model by enforcing consistency in definitions, units, and time conventions. For each decision period, it produces a versionable **data snapshot**, ensuring that all scenarios are comparable on a common data baseline.

The **model layer** is the computational core that generates the KPIs in Table 1 and operates through four interconnected modules. **M1 (microsimulation core)** computes, under each scenario, the gross-to-net transformation, tax and contribution burdens, transfer entitlements, and public-finance impacts, thereby producing outputs such as **disposable income/net income changes** and **budgetary effects**. **M4 (distribution/adequacy module)** combines the household- and worker-level outputs generated by M1 with wage-distribution information to derive distributional KPIs such as the **share of affected workers**, **wage compression**, the **position of the minimum wage within the wage distribution**, and **changes in poverty risk**. **M3 (price/cost-of-living channel module)** translates the scenario-induced cost shock—especially in low-wage-intensive sectors—into the price level and the essential-basket index via parametric pass-through assumptions. This enables KPIs such as **real purchasing power** and the **essential basket coverage ratio** to be measured in real (price-adjusted), rather than nominal, terms, and thus provides feedback to M4's adequacy assessment. Finally, **M2 (sectoral stress-test module)** summarizes, at the sectoral/regional level, wage-cost and adjustment pressures implied by the scenario (using indicators such as minimum-wage proximity intensity, cost increases, and employment vulnerability), producing risk/KPI outputs such as a **sectoral employment pressure index (with uncertainty bands)** and making explicit where sensitivities are concentrated.

The **scenario layer** version-controls alternative minimum wage options (including the level, increase rule/indexation, coverage, and associated assumption sets) under a unique "scenario identity." This ensures that each scenario is executed on the same data snapshot and the same family of rule sets, thereby enabling consistent, like-for-like comparisons of the KPI baskets defined in Table 1 across scenarios.

Finally, the **governance/reporting layer** standardizes the **audit trail** that links each KPI value back to the corresponding criterion–data–module chain in Table 1, together with **version records** (data snapshot, parameter/assumption set, and module version) and **reporting packages** (a stakeholder summary plus a technical appendix). In doing so, it ensures that the resulting evidence is incorporated into the decision process in a transparent, auditable, and reproducible manner. Within this framework, the layers define "architectural responsibility domains," whereas the modules (M1–M4) denote the KPI-producing "computational components," primarily within the model layer; Table 1 provides the mapping logic that connects these two levels.

Figure 1 offers a schematic, left-to-right process representation of MWDT's main stages. The criterion mapping in Table 1, in turn, clarifies which layers in this process are responsible for producing which outputs.

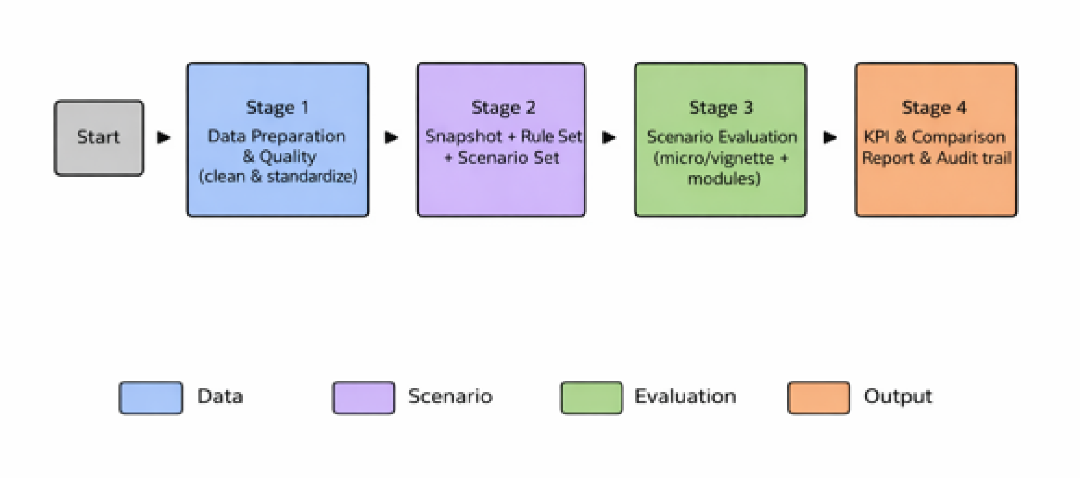


**Figure 1. Main stages of the MWDT: data integration → modeling core → scenario analysis/evaluation → governance/reporting.**

In the first stage (Data), inputs such as wage/employment and price indicators, as well as tax-contribution-transfer rules, are cleaned, standardized, and undergo quality controls. In the second stage (Scenario), this validated dataset is fixed as a versioned "snapshot," and the rule set to be applied along with the set of scenarios to be evaluated are defined. This allows different policy options to be compared under identical reference conditions. The third stage (Calculation) involves running the scenarios through micro-simulation/vignette and related modules, generating a common set of outputs for each scenario. In the fourth stage (Output), the results are compared based on KPI baskets, findings are reported, and traceability is ensured through an audit trail record containing information on the data version, assumptions, and model execution used.

On the other hand, Figure 2 illustrates the MWDT's "operational protocol" (algorithmic workflow): data quality control and feedback loops, snapshot/rule set selection, scenario iteration, the microdata/vignette distinction, optional second-round effects, and KPI generation are all integrated within a single flow.

The process begins with the ingestion of data sources related to wages/employment, prices, and tax-contribution-transfer rules. This is followed by data cleaning and standardization to ensure definition/unit/period consistency, along with the execution of data quality control. To ensure comparability, the dataset is locked as a versioned snapshot (SnapID) and prepared for scenario execution in conjunction with the selected rule set (Ruleset v). Subsequently, the scenario set is defined and scenarios are evaluated iteratively. If microdata is available, the M1 microsimulation core calculates gross-to-net and budgetary effects. In the absence of microdata, the vignette module generates gross-to-net outputs for typical households. These core outputs are then extended through the M4 distribution/adequacy calculations (e.g., share of affected workers, wage compression, poverty risk) and the M3 price/living cost channel (e.g., real purchasing power, basket coverage ratio) to produce the KPI basket defined in Table 1. The M2 sectoral stress test module facilitates the interpretation of scenario effects within the context of sectoral/regional vulnerabilities. Optionally, second-round effects can be incorporated into the assessment through sensitivity/band analysis. In the final stage, KPI baskets are compared across scenarios, reported, and an audit trail is recorded for each run, linking it to the specific data version, rule set, assumptions, and module outputs, thereby ensuring full traceability. The step-by-step procedural definition of this workflow, summarized in Figure 2, is provided in Algorithm 1 presented in Appendix A (see Appendix A, Algorithm 1).

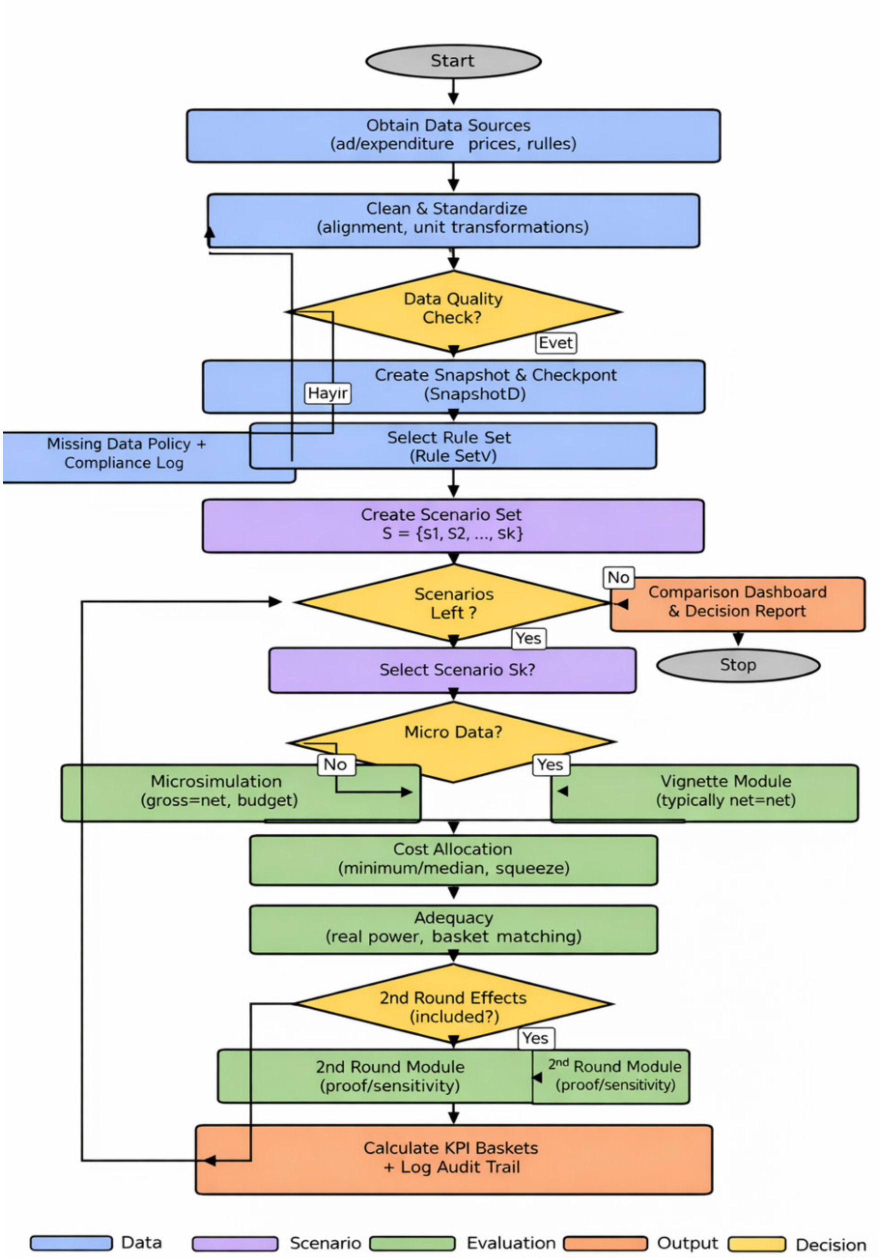


**Figure 2. MWDT scenario evaluation flowchart: validation → execution → KPI computation → sensitivity analysis → reporting.**

The most critical point to consider at this juncture is that for the MWDT to be usable as a reliable decision-support infrastructure in decision-making processes, the following three components must be designed in an integrated manner: (i) validation, (ii) uncertainty management, and (iii) phased institutionalization.

Therefore, in the first stage, the disposable income distribution and tax/contribution and transfer magnitudes produced by the microsimulation core for a selected base year must be validated at a

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"baseline" level by checking their consistency with official statistics to the greatest extent possible. In the second stage, because second-round effects—particularly regarding employmen t and price pass-through—inherently involve structural uncertainty, results should be reported not as single-point estimates but via **scenario bands and sensitivity analyses**. It must be clearly indicated which KPIs are sensitive to which assumptions.

In the final stage, the maturity of the MWDT as a digital twin should evolve from a "one-off analysis" approach to an **"institutional learning cycle."** Initially, it should be implemented at a digital shadow level (vignette + micro core + basic KPI dashboard), with its data coverage and modules gradually expanded. A systematic calibration mechanism must be established by monitoring post-decision outcomes.

This three-pronged approach strengthens the MWDT's claim to transparency and traceability (audit trail) while simultaneously creating a sustainable decision infrastructure that enables different stakeholders to deliberate based on a **common indicator framework**.

V. Discussion, Applicability, and Policy Implications

In light of the discussion thus far, the core proposition of the MWDT is to transform minimum wage setting from a choice of a single "increase rate" into a decision-support process where the criteria indicated in legislation are translated into measurable indicators (KPI baskets), uncertainty is reported through band/sensitivity analyses, and outputs are supported by a traceable chain of evidence (audit trail), thereby enabling decision-makers to utilize this support system. In this framework, the MWDT is positioned not as a substitute for the normative dimension of the decision (goals/priorities), but as an analytical infrastructure that strengthens the capacity for social dialogue and evidence-based justification (ILO, 1970; European Parliament and Council of the European Union, 2022).

To demonstrate the workflow for two distinct nominal increase scenarios, such as $s_1$ = 25% and $s_2$ = 35%, within the Minimum Wage Digital Twin (MWDT) framework, the system processes each scenario through a sequence of integrated modules. For a given scenario, it first executes the microsimulation module (M1) to compute gross-to-net wage conversions across household typologies, model interactions with tax and benefit systems, and quantify the direct fiscal impact (first-round effects). Subsequently, the price/livelihood channel module (M3) estimates the potential pass-through effects on selected consumption basket items and updates the relevant cost-of-living indices. In parallel, the sectoral stress-test module (M2) assesses potential employment adjustments and informality risks, particularly in low-margin and labour-intensive sectors. Finally, the distribution/adequacy module (M4) calculates indicators related to wage adequacy—benchmarked against a mandatory needs basket—and compliance. All outputs are then synthesised on a central dashboard for comparative analysis against predefined KPI bands, accompanied by sensitivity assessments. The entire set of results, along with the exact parametric configuration (Ruleset_v) and a unique snapshot identifier (SnapID), is archived in a reproducible format within the AuditTrail, thereby ensuring full traceability and auditability of the policy simulation.

Consequently, the institutional value of the MWDT lies in rendering the data and assumptions underpinning minimum wage determination visible under a “common reference.” The snapshot approach ensures that the data–rule set used at the decision moment is frozen, allowing the exact same run to be reproduced later. The comparative presentation of KPI baskets (adequacy, distribution, fiscal, sectoral pressure, etc.) across scenarios reframes commission discussions not around a “single number,” but around an indicator space where trade-offs are made explicit. This proposed structure thereby facilitates two-tiered reporting for stakeholders: (i) a decision summary and visual dashboard; and (ii) a technical appendix (data dictionary, rule set version, assumptions, and sensitivity outputs).

Furthermore, the MWDT can be designed to start at a “digital shadow” level, even in contexts with limited access to microdata. In such cases, a vignette module can be activated in place of the M1 microsimulation core, transparently demonstrating the gross-to-net conversion and the effects of rule changes on typical households (OECD, 2022). If microdata access is secured, the M1 microsimulation core will produce more comprehensive household-level distributional results and public finance effects. However, this necessitates the clarification of data security (privacy, anonymization, secure processing environment) and data-sharing protocols. Here, the data dictionary, variable definitions, and version management (digital thread) emerge not merely as technical necessities but as governance imperatives.

Second-round effects, such as the impact of minimum wage increases on employment and prices, inherently involve structural uncertainty. Within the MWDT, this uncertainty is reported not as a single point estimate but through the generation of bands (intervals) based on elasticity ranges and alternative behavioral assumptions, along with sensitivity runs. The M2 stress test module makes sectoral/regional vulnerabilities and areas of concentrated cost pressure visible, while the M3 price channel module recalculates the impact of nominal wage increases on purchasing power and basic needs basket coverage ratios in real terms. This approach does not eliminate model risk; rather, it strengthens the rationale for decisions by making transparent which assumptions give rise to that risk.

Three steps are deemed critical for the MWDT to evolve into a reliable decision-support infrastructure. First, baseline validation must be conducted; it should be demonstrated that for a chosen base year, model outputs (disposable income, total tax/contributions, transfer amounts) are generated consistently with official statistics to the greatest extent possible. Second, uncertainty management must be standardized, particularly for employment and price channels, through band/sensitivity reporting; assumption sets should be archived along with scenario identifiers. Third, phased piloting should be designed: starting at a digital shadow level (vignette + basic KPI dashboard), microdata integration and the scope of the M1 core can be gradually expanded. To these three critical steps, a final stage should add calibration based on post-decision outcomes, thereby strengthening an institutional learning cycle. This phased approach aligns with the digital model–digital shadow–digital twin maturity continuum (Kritzinger et al., 2018).

While this study designs the MWDT as a modular architecture, it does not aim to fully represent second-round effects (employment, price pass-through, informality response) with a comprehensive structural model. Therefore, the MWDT's outputs should be evaluated in conjunction with complementary analyses, especially during periods when macro-general equilibrium effects are strong.

For future research, this study highlights several priority areas: (i) strengthening microsimulation capacity for Türkiye and its integration with local model infrastructures (e.g., TURKMOD; Erol, 2022); (ii) enriching data at the sectoral/regional level and calibrating M2 stress tests; (iii) extending the M3 price channel with more detailed basket definitions and inflation dynamics; (iv) designing governance for integrating results into decision processes (access roles, transparency standards, social dialogue protocols); and (v) institutionalizing back-testing procedures for retrospective validation.

## CONCLUSION

This study proceeded from the premise that minimum wage setting should not be viewed as merely determining a single rate of increase. It is founded on the recognition that the minimum wage is a multidimensional policy instrument that simultaneously generates effects on welfare, distribution, firm costs, price levels, and public fiscal balances. Consequently, the study demonstrates that the minimum wage decision must be approached as a multi-criteria decision problem involving trade-offs between distinct objectives. The core question addressed is whether, within this multidimensional decision space, it is possible to design an institutional analytical framework that strengthens the chain of evidence for the decision, rather than seeking a single “correct number.”

In response, this article proposes a modular decision-support architecture called the Minimum Wage Digital Twin (MWDT). At the heart of the MWDT lies a traceability framework that systematically links the criteria indicated in legislation to measurable indicators. This pipeline, which transforms criteria into KPI outputs via defined data domains and computational components, enables scenario comparisons on a common reference. Thus, the decision process is elevated to the logic of a “scenario laboratory” that is repeatable and auditable, based on evaluating different proposals under the same data version and the same rule framework. In scenario runs, first-round effects (gross-to-net conversion, tax/contribution/transfer interactions, and direct public fiscal impacts) and second-round effects (employment/informality responses and price pass-through) are reported as distinct module outputs; uncertainty bands and sensitivity analysis are transparently reflected in the decision set.

The scientific contribution is to present an architectural artefact that transcends the level of “singular analysis” by adapting the digital twin approach to policy design. By concurrently presenting (i) a traceability matrix that translates requirements (criteria) into a measurement-output structure, (ii) a layered architecture based on the distinction between data–model–scenario–governance, and (iii) a protocol logic that standardizes scenario execution, the article proposes a generalizable framework for how decision-support systems can be designed at an institutional scale.

The practical contribution lies in positioning the MWDT not as an automation that “makes the decision,” but as an infrastructure aimed at justifying the decision and strengthening stakeholder communication. This approach provides a more transparent evaluation ground by making visible the impact profile of each scenario across multiple indicators, rather than centering debate on a single number. Simultaneously, it renders the data and assumptions underpinning the decision rationally traceable. In this way, the MWDT fosters a capacity for "evidence-based comparison" within social dialogue and enhances the accountability of the decision-making process.

Finally, as discussed in Section V regarding the design risks, data governance requirements, reporting of model uncertainty, and phased institutionalization strategies associated with implementing the MWDT, the success of this architecture depends on institutional process design as much as on technical validation. In this context, the study concludes that a digital twin design that strengthens the methodological backbone of minimum wage setting and standardizes traceability and comparability represents a meaningful development path at both academic and institutional levels.

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## Appendix A

***Algorithm 1. MWDT scenario evaluation procedure (procedural counterpart of Figure 2)***

**Input:**

- Data sources D: wages/employment, price indices, tax–contribution–transfer rules, context variables
- Ruleset version Ruleset_v
- Scenario set S = {$s_1$, …, s_K}
- Modules: M1 (microsimulation), M2 (sectoral stress test), M3 (price/cost-of-living channel), M4 (distribution/adequacy)
- Optional second-round parameters Θ (sensitivity/band analysis)
- Output:
- Scenario-specific KPI baskets {KPI(s_k)} and a comparison dashboard
- Audit trail AuditTrail: SnapID, Ruleset_v, assumptions, module versions, and run metadata

**Steps:**

1. Import the data sources D (wages/employment, prices, rules, context).

2. Apply cleaning and standardization (definition harmonization, unit/time transformations, and data-dictionary checks).

3. Run data quality control.

   3.1 If critical missingness/inconsistencies are detected, generate a missing-data policy and a warning log; perform the required corrections and return to Step 2.

4. Create a data snapshot SnapID and lock the dataset in a versionable form.

5. Select the ruleset/parameters Ruleset_v and bind them to the scenario execution.

6. Construct the scenario set S = {$s_1$, …, s_K}.

7. For each s_k ∈ S:

   7.1 Check the availability of microdata.

   7.2 If microdata are available, run M1 and generate outputs for gross-to-net conversion, taxes/contributions, transfers, and fiscal impacts.

   7.3 If microdata are not available, run the vignette module and produce gross-to-net outputs for representative household types.

   7.4 Run M4: compute wage-distribution and adequacy indicators (e.g., share of affected workers, wage compression, poverty-risk change).

7.5 Run M3: apply the price/cost-of-living channel and produce real purchasing-power and basket-coverage indicators; propagate these adjustments to the relevant adequacy KPIs.

7.6 Run M2: generate sectoral/regional stress and vulnerability indicators (with banded reporting where applicable).

7.7 If second-round effects are to be incorporated, run sensitivity/band analysis under Θ and record the results.

7.8 Construct the KPI basket KPI(s_k) (following the KPI framework defined in Table 1).

7.9 Update AuditTrail with run records (SnapID, Ruleset_v, assumptions, module versions, timestamp).

8. Generate the scenario comparison dashboard and report package based on {KPI(s_k)}.

9. Comparison and reporting: produce the scenario comparison dashboard from {KPI(s_k)} and compile the report package (“stakeholder summary + technical appendix”).

10. Stop: archive all outputs and retain run metadata to ensure reproducibility.