In this document, the review comments are in black, our responses are in blue.
The changes made in the manuscript for this revision are written in red.

Reply to the comments by Referee #1

This paper downscales national GDP estimates across a global grid of 30 x 30 arcsec pixels. This is an interesting objective and recognizes that little work has indeed been done to move beyond people-based GDP-scaling to one that also considers the distribution of economic activities. The methodology as well as several involved assumptions and uncertainties are described transparently.

However, I have several concerns regarding this paper and the quality of the dataset. In addition to the detailed comments provided below, overall, it appears that the paper attempts to integrate two papers rather than producing a single focused paper; the paper namely both documents the creation of a global GDP map, and attributes much of the paper's attention (see e.g. the discussion section) on Thailand and Thai-specific issues.

> Thank you very much for your constructive comments which are very helpful for improving the manuscript.

We've made significant revisions since the last version, incorporating various comments. The two main changes are:

1. Modified spatial distribution methods for Service and Agricultural GDP.

2. Expanded validation scope from only Thailand to a global scale.

These changes have refined the rationale behind our spatial distribution methods for each sector's GDP. As a result, we've confirmed that the spatial distributions now align with sub-national statistical data across numerous regions, not just Thailand. The following sections will detail how the new manuscript addresses specific concerns raised in previous comments. For more details of the validation, please refer to the Results section in the main text.

①The paper augments established European Commission data to differentiate global land use by residential, non-residential, and cropland uses. However, it is assumed (p.6) that residential use ("RES") represents the service sector of the economy. That is a very rough proxy given that this includes the housing of those who work in non-residential areas (the "industrial sector"), as most people do.

> We are sincerely grateful to you for the comment. This paper focuses on "where GDP is generated" for the allocation of GDP, and does not consider "where the employees and users who generate GDP live." "Where the employees and users who generate GDP in each sector live" requires consideration of transportation networks and the estimation becomes complicated, so this is not considered in this paper.

Focusing on "where GDP is generated in each sector," it is possible to distribute simply by using existing global datasets by making the following assumptions:

・The service sector generates GDP in the Residential area where direct consumers exist.

・The industrial sector generates GDP in the Non-residential area where factories are located.

We understand that the fact that we do not consider the relationship between GDP production locations for each sector and workers' residential spaces is a limitation of this study, as you pointed out. We added this point to the Discussion part, as shown below.

"Related to this limitation of the indirect production stoppage, it is important to recognize that the methodology, including that of this paper and previous studies, which determines the GDP produced in each pixel using indicators such as GDP per unit area, overlooks the fact that labor supplied from remote locations is necessary for GDP production. To rephrase this with the example of a factory affected by a disaster: while the GDP output itself occurs at the factory's location, the workers who carry out the production reside in surrounding or remote areas. Therefore, if a disaster occurs in these remote residential areas, the GDP output should cease. However, pixel-based calculation methods would fail to represent this cessation of GDP output as long as the factory's pixel is unaffected. This is considered a non-negligible impact in regions where economic activity and residential areas are clearly separated, but quantifying this impact on a global scale is currently challenging. Alongside future research on regional differences in GDP per unit area, this remains a limitation that we must consider moving forward."

Moreover, the non-residential areas being classified as the ‘industrial’ sector, if I understand the classification scheme correctly, pools together any services and manufacturing and other sectors as ‘industrial,’ separately from ‘services’. This appears to be inappropriate and thus call into question whether the global map is able to distinguish between sectors. The data do appear to possibly reasonably allow for a global GDP map, without sectoral differentiation, that downscales national GDP estimates given local non-residential land use.

> Thank you for your valuable comments and suggestions. We appreciate your attention to detail and the opportunity to clarify our industry classification.

To address your concern regarding the clarity of industry classification in this paper, we have used the following definitions based on the International Standard Industrial Classification (ISIC) Rev 4 codes from the World Bank's World Development Index:

Agriculture: ISIC 01-03 (A)

Service: ISIC* 50-99

Industry: ISIC 05-43 (B-F)

* It should be noted that only the Service sector is based on ISIC Rev. 3

For further details, please refer to the following URL:

ISIC Rev 4, https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf

ISIC Rev 3, https://unstats.un.org/unsd/classifications/Econ/Download/In%20Text/ISIC_Rev_3_English.pdf

This means that our "industry" classification does not include "wholesale" or "professional services," which are categorized under "Service" in the World Bank's definitions. We believe that our dataset, with this classification method, aligns with widely used classification approaches. We acknowledge that this definition was not explicitly stated in the original manuscript. In response to your feedback, we have added the classification details mentioned above to the manuscript to ensure clarity for our readers, as shown below.

Sector	Definition of ISIC
Agriculture	ISIC 01-03 (A)
Service	ISIC* 50-99
Industry	ISIC 05-43 (B-F)

*It should be noted that only the Service sector is based on ISIC Rev. 3.

Table 2: Definition of each sector, based on the International Standard Industrial Classification (ISIC) Rev 4, in the GDP data by the World Bank (2023).

Additionally, we present a comparative analysis between the National Land Use Database (NLUD) land classification data in the United States and the Global Human Settlement Layer (GHSL) data (RES/NRES categories) used in this paper.

The following table (Table R1) illustrates the proportion of areas classified as RES and NRES in GHSL within the service and industrial sectors of the NLUD land classification. The table reveals that a significant portion of service areas is identified as RES areas, while approximately half of the industrial areas are classified as NRES areas.

Table R1: Percentage (Area-Based) of GHSL Residential Area (RES) and Non-Residential Area (NRES) within NLUD Land Use Categories (Service and Industry)

	Service	Industry
NRES	9.2%	41.6%
RES	90.8%	58.4%

Based on this table, we argue that using RES areas as a proxy for service industries is reasonable. For NRES areas as a proxy for industrial industries, the results suggest that large-scale factories are classified as NRES areas, while small to medium-sized factories adjacent to residential areas are classified as RES areas. Therefore, assigning all industrial activities to NRES areas may not accurately represent industrial GDP in regions with small to medium-sized factories, which is a significant limitation of this study. This limitation has been added in the revised version of this paper.

However, we believe that this limitation does not significantly undermine the importance of our research. Given the absence of detailed global land classification data, finding a perfect proxy is challenging. Despite the inability to accurately represent the locations of small to medium-sized factories, which account for approximately 30% of manufacturing GDP (in the US, for example), our dataset still captures the industrial GDP distribution of large-scale factories, which contribute to the remaining 70% of GDP.

②Claims such as “in the United States, industrial GDP is widely dispersed regardless of urban areas” are interesting but also bold, given that the observation comes from the East coast of the USA which is relatively agglomerated (how are “cities” defined in the paper?) and paired with serious uncertainty, given that the validation of the global dataset is done for Thailand but not for the rest of the world. Ideally, analytical claims should be made only for regions for which the data are also validated to not over-assert the validity of the data that underpin the insights. In any case the validity of the findings could be asserted more carefully. It would also be helpful to compare the insights against to standing knowledge, whether from estimates in other papers or also reports (e.g., such as the 2012 ‘Urban America’ McKinsey report).

> Thank you for pointing out the limitation of our current validation, which focuses solely on Thailand. We acknowledge that this raises concerns about the generalizability of our findings to other regions.

To address this, we expanded our validation globally. This revealed that the map exhibits a distribution consistent with actual sub-national statistics across many regions outside of Thailand. Consequently, we removed the specific reference to the U.S. and instead focused on Thailand, Japan, and the agricultural sector in Paris, where the map's accuracy is well-established, shown as follows. Furthermore, these specific mentions are confirmed to align with the generally recognized characteristics of each respective region.

“In the figure of Japan, Japan's three major metropolitan areas—Tokyo, Osaka, and Aichi—shows variations in sectoral distribution, despite their common characteristic of high population concentration. In the GDP map, the service sector predominates in the coastal areas of Tokyo and Osaka, which are marked by high population and service industry presence. In contrast, Aichi's coastal regions exhibit a widespread predominance of industrial GDP. Industrial GDP is not uniformly distributed across the entire Aichi area. Within Aichi, the more inland urban center, such as the Nagoya area, shows a prevalence of the service sector, with industrial GDP concentrated in coastal areas. These findings align with Aichi's higher proportion of industrial GDP compared to Tokyo and Osaka (DOSE, 2024), and the formation of an extensive industrial belt along its coastal regions. This dataset facilitates the depiction of detailed distributional differences within these areas.

When comparing central Bangkok with its southeastern region, a similar pattern emerges as a case in Japan. The southeastern area, specifically the Eastern Seaboard and Eastern Economic Corridor (EEC) centered around Laem Chabang Port, has developed as an industrial hub. In this region, industrial GDP predominates over service sector GDP. Regarding the distribution of agricultural GDP, Japan shows fewer pixels where agricultural GDP is dominant, largely because much of its agricultural land is located relatively close to urban areas. However, in Thailand and France, extensive areas with dominant agricultural GDP are observed around metropolitan centers like Bangkok and Paris. For instance, Figure 4, which shows only agricultural GDP for France, illustrates that agricultural GDP is minimally developed around densely populated Paris. Conversely, it depicts widespread agricultural activity in the less populated surrounding regions.”

③The paper could do more to underpin assumptions with field knowledge, in particular on how the assumptions could drive the outcomes observed in the global map. For instance, on p.6 it is stated that “the service GDP was distributed only in pixels within cities and the amount of distributed GDP was proportional to the population density of the city where the pixel is located”. This appears to in effect assume away any service sector presence outside of urban areas, which is unrealistic, and that the amount of GDP attributed to a pixel is contingent on city density —other than the size of the city— which indeed drives productivity but not overall output levels as those instead respond predominantly to city scale.

> Thank you for your comment regarding the definition of service GDP production areas in our study. As you correctly pointed out, our previous methodology confined service GDP generation to areas within urban polygons as defined by the GRUMP dataset. However, through the process of re-validation and improvements in the GDP distribution methodology, we changed the methods and modified thoroughly the rationale of the distribution methods for agriculture and service sectors, including , as follows.

“2.1.3 Land-use-based agriculture sector GDP

To better reflect the spatial structure of production activities, we introduce the supplier effect, which assumes a beneficiary-supplier relationship. Specifically, agricultural production occurring in peri-urban or rural areas surrounding major population centers is regarded as supplying food and resources to those urban beneficiaries. These agricultural zones, while themselves sparsely populated, are functionally integrated with the urban economy. Therefore, they are expected to exhibit higher GDP values than similarly sparse regions that are not spatially or economically connected to urban demand. To capture this spatial interdependence, the supplier effect applies a distance-decay reallocation from beneficiary pixels (population-based GDP map) to nearby supply-side pixels, namely those identified as MCROP. Technically, this is implemented as a linear decay function, in which full weight is given within an inner threshold of 150 km, and weight decrease linearly to zero at an outer threshold of 300km.

$$w_{ij} = if\ d_{ij} \leq d_{in}: 1;\ if\ d_{in} < d_{ij} \leq d_{out}: 1 - (d_{ij} - d_{in})/d_{in};\ if\ d_{ij} > d_{out}: 0 \quad (2)$$

2.1.4 Land-use-based service sector GDP

Similarly, PB of the service sector is reallocated to residential areas (RES) by applying the supplier effect. The rationale here differs slightly from that for agriculture. Grid-scale population data (e.g., at 30-arcsecond resolution, or approximately 1 × 1 km per pixel) are too fine to represent realistic service usage, since people commonly travel more than 1 km by car or public transportation to access services (Ciccone and Hall, 1996). Therefore, this reallocation is designed to represent commuting patterns, where service activities in peri-urban zones support nearby urban demand centers. In this context, we use a supplier effect with an inner threshold of 25 km (representing high-intensity interaction) and an outer threshold of 50 km, beyond which service contributions are assumed negligible.”

Further comments

- The narrative flow and grammar should be checked closely throughout the manuscript (see, e.g., the first five sentences of the abstract).

> Thank you for your helpful feedback. We have revised the abstract as follows, incorporating your suggestions:

“Global risk assessments of economic losses by natural disasters while considering various land uses is essential. However, sector-specific, high-resolution pixel-level economic data are not yet available globally to assess exposure to local disasters such as floods. In this study, we employed new land-use data to construct global, spatially distributed map of sector-specific gross domestic product (GDP). We developed three global GDP maps, SectGDP30, in 2010, 2015, and 2020 for service, industry, and agriculture sector, with 30

arcsec resolution. The map (SectGDP30) demonstrates strong consistency (R^2 > 0.9) with actual sub-national statistical data, exhibiting superior alignment compared to conventional GDP maps (PB-method) reliant solely on gridded population information. The methodology refined GDP distribution for specific sectors. Industry GDP was more accurately mapped using non-residential land areas as a proxy, effectively capturing its localized concentrations. Agriculture GDP's accuracy improved by incorporating cropland data and a distance-based distribution assumption from population agglomeration. Application of this dataset in estimating flood-induced business interruption (BI) losses confirmed the map's capacity to represent inter-sectoral differences in estimated losses, reflecting varied hazard spatial distributions. This underscores the importance of considering sector-specific spatial patterns for accurate disaster damage assessment. These maps serve as a foundational tool for estimating detailed, sector-classified economic losses, enabling precise calculation of sector-specific impacts from diverse natural disasters worldwide. These global sectoral GDP maps (SectGDP30) are available at https://doi.org/10.5281/zenodo.13991673 (Shoji et al., 2024)."

We also made some modifications throughout the manuscript based on your other comments.

Reply to the comments by Referee #2

This manuscript develops a sectoral GDP map (for service, industry, and agriculture) at 30 arcsec resolution and explores its application in disaster risk analysis. The authors generate land-use data and population data to downscale national-level GDP to derive spatial distribution results. By providing high-resolution global sectoral GDP maps, this dataset offers more detailed geospatial information to support disaster risk analysis and economic loss assessments.

The methodology and limitations in the manuscript are clearly discussed. However, the validation and analysis of the data itself need to be strengthened. Additionally, the Discussion section should be reconsidered in terms of its length and content.

> Thank you very much for your constructive comments which are very helpful for improving the manuscript.

We've made significant revisions since the last version, incorporating various comments. The two main changes are:

1. Modified spatial distribution methods for Service and Agricultural GDP.

2. Expanded validation scope from only Thailand to a global scale.

These changes have refined the rationale behind our spatial distribution methods for each sector's GDP. As a result, we've confirmed that the spatial distributions now align with sub-national statistical data across numerous regions, not just Thailand. The following sections will detail how the new manuscript addresses specific concerns raised in previous comments.

Specific Comments:

1. The Introduction section should include a discussion of other existing GDP spatial datasets, covering their methodologies, spatial resolutions, and the challenges in existing GDP mapping processes.

> Thank you for your feedback. We've updated the description of GDP dataset products in Introduction, based on your comments, as follows.

“GDP maps developed using these methods are generally created for specific purposes, such as disaster damage estimation, and are therefore not typically released as standalone datasets or products. Among those that are publicly available, "Downscaled gridded global dataset for gross domestic product (GDP) per capita PPP over 1990–2022" by Kummu et al., 2025, is notable. This dataset generates gridded GDP map products with resolutions ranging from 30 arcmin to 30 arcsec for each year since 1990, based on sub-national statistics released by various countries and utilizing population count maps.”

Previously, existing research primarily created GDP maps using population data as a proxy. These maps were generally developed as simplified tools for specific purposes, such as disaster damage estimation, and were not typically released as public datasets or products. Consequently, methods relying solely on population data as a proxy were widely adopted. Currently, the only publicly available pixel-level global GDP distribution map product is Kummu et al., 2025 (previously Kummu et al., 2018). We believe the limitations of this product and the methods using population data as a proxy are already addressed in the original manuscript.

2. The study assumes that service-sector GDP is primarily distributed in high-population-density areas, but certain economic activities—such as high-end financial services and tourism—do not necessarily follow this pattern. For example, the financial district in Manhattan has an extremely high GDP density despite relatively low residential population density. Have the authors considered such spatial distribution patterns of economic activities?

> Thank you for your insightful comment regarding the handling of service GDP. We appreciate your attention to this detail.

As you pointed out, using fine-grained municipal-level population density could indeed lead to issues. However, our approach leverages the GRUMP dataset, which defines urban

polygons based on nighttime light data, effectively capturing spatially contiguous urban areas. This means that large metropolitan areas, such as the area encompassing Manhattan, are treated as a single urban entity. Therefore, while Manhattan itself may have a high concentration of service sector activity, the GRUMP polygon for this area also includes surrounding residential areas, resulting in a high overall population density for the urban entity. This, in turn, leads to a correspondingly high allocation of service sector GDP within that defined urban area. We believe this approach provides a reasonable representation of the spatial distribution of service sector GDP at the scale of analysis used in this study.

June 30, 2025 Addendum: While the spatial distribution method for service sector GDP, as referenced in this comment, has been revised in the current update, the fundamental approach of distributing it proportionally to the population within a given area remains unchanged. Therefore, the explanation above still applies to the new manuscript.

3. Why did the authors choose the GRUMP dataset to account for urban effects instead of other datasets? A brief explanation for this choice would strengthen the methodology section.

> Thank you for your question regarding the choice of urban polygon dataset. We considered several options, including:

1. GRUMP
2. GHS-Urban
3. World Urban Areas (available in Esri ArcGIS)

We ultimately selected GRUMP for the following reasons. The GHS-Urban dataset, while comprehensive, delineates urban areas at a very fine-grained level. This resulted in the splitting of what are generally considered single urban agglomerations into multiple, separate urban polygons. This fragmentation led to unrealistically high population densities in some polygons when implementing the city-effect, which in turn skewed our service GDP estimates. Therefore, we deemed GHS-Urban unsuitable for our specific application.

The World Urban Areas dataset offered polygons that were very similar to those in GRUMP. However, as it is not openly accessible, we opted for the open-source GRUMP dataset to maintain transparency and reproducibility in our research.

June 30, 2025 Addendum: As a result of this revision, the GRUMP dataset is no longer used for the spatial distribution of service sector GDP.

4. The validation was conducted in only seven regions of Thailand, but Thailand's economic structure may not be representative at a global scale. For example, Western economies are

more dependent on the service sector, while industrial and agricultural distributions vary significantly across different regions. Have the authors considered additional validation in countries with different economic structures, such as the United States, China, or Germany?

> We appreciate your observation regarding the limited scope of our current validation, which is confined to Thailand. We recognize that this raises questions about the broader applicability of our results. Considering your valuable comment, we expand the target area of validation from only Thailand to worldwide. The result showed the strong consistency with the sub-national scale statistics in many areas in the world. For more details, please refer to the Results section in the main text.

5. A comparison with other existing GDP products or remote sensing proxies should be included to better highlight this dataset's advantages.

> Thank you for your comment regarding the comparison with existing GDP products and remote sensing proxies. We understand your question and would like to clarify our approach.

As you mentioned, GDP distribution has traditionally been conducted at scales ranging from national to municipal levels, based on statistical information. Studies that generate GDP maps at the grid scale, as we do in this paper, are limited to those mentioned in the Introduction.

Regarding remote sensing proxies, existing research generally falls into two categories: land cover or population distribution. Previous studies have primarily focused on population distribution. Our work represents, to the best of our knowledge, the first attempt to utilize land cover as a primary proxy for generating a global, high-resolution GDP map.

Therefore, when comparing our work to existing GDP products and remote sensing proxies, the most relevant comparison is indeed the one we already provide in the manuscript with our population-based map. This comparison serves to highlight the key differences and potential advantages of using land cover as a proxy, as opposed to the more traditional approach based on population distribution. We believe this comparison effectively addresses the spirit of your question regarding comparison with existing products and proxies.

6. Since the study aims to provide a globally applicable dataset, the Thailand case study in Section 4.1 should be presented as a supporting example rather than the main focus. It is recommended that the authors strengthen the discussion of the dataset itself, particularly regarding accuracy assessment, comparisons with existing datasets, spatial details, and temporal variation analysis. Additionally, by reducing the emphasis on the Thailand case

study and discussing broader disaster analysis applications, the authors can better highlight the dataset's global applicability.

> Thank you for your helpful feedback. As mentioned in our response to another comment, we added validation for regions beyond Thailand in the revised manuscript. To accommodate this and maintain a balanced focus, we reduced the content related to the flood damage analysis in Thailand. This allowed us to shift the emphasis of the manuscript towards the broader validation efforts, including the comparison with population-based maps, and provide a more comprehensive assessment of the dataset's global applicability.