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Regional Wealth Data Acquisition and Modeling: Innovations Needed for Advancement in Sustainable Wealth in Energy-Rich Regions

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Abstract: National-level studies present the development techniques and challenges of sustaining energy-rich economies, particularly those in the developing world. However, examples of the application and interpolation of these broad-scale analyses to the regional level are scarce. Conversely, methods used at national levels are often infeasible when using higher-resolution regional or local data. Ultimately, progress in developing, managing, and advancing regional wealth databases and models is significantly missing from the literature. Herein, proposed pathways and general development frameworks are presented based on the presumptive constancy of total capital stock. Processes are outlined for acquiring information (data) and developing models to serve as a basis for qualitative and quantitative analyses of sustainable development policymaking decisions. We present a discussion around the sustainable wealth of energy-rich regions, and we suggest potential workflow methods for developing regional wealth knowledge bases and regional wealth models (RWMs). Structural scaffolding opportunities are presented for the validation of RWMs using pilot studies, followed by the process of disseminating modeling outcomes. Finally, we offer recommendations and needed innovations to advance the development of RWMs. The objectives of this article are not to provide a comprehensive literature review or consider all potential perspectives but rather to identify tools and necessary enhancements to established methods for assessing and modeling regional wealth and provide an inroad for readers wishing to learn more. The increased awareness generated through this article will mobilize assistance and generate new information that will strengthen this emergent area of research to intensify regional wealth sustainability for future generations.

Keywords: regional sustainability; energy-rich regions; regional wealth; energy resources; geospatial technologies; knowledge base

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Citation: Hubbart, J.A.; Ghadimi, H. Regional Wealth Data Acquisition and Modeling: Innovations Needed for Advancement in Sustainable Wealth in Energy-Rich Regions. *Challenges* **2023**, *14*, 51. https://doi.org/10.3390/challe14040051

Academic Editor: Susan Prescott

Received: 18 October 2023
Revised: 28 November 2023
Accepted: 5 December 2023
Published: 7 December 2023

1. Introduction

1.1. Background

Energy-rich regions (ERRs) often have significant wealth in the form of energy resources, but some ERRs also include large low-income populations. This dichotomy of *rich region–poor people* is nowhere as pronounced as in rural ERRs. Despite vast wealth in natural resources, many communities in these regions fall below national levels of well-being and standards of living. An extensive body of literature addresses energy resource depletion and inter-generational equity, mainly at national levels [1–4]. For example, authors have highlighted the need for an equitable distribution of sustainable energy resources, with the latter emphasizing the negative impacts of traditional energy use [5–7]. Recent studies have also attempted to focus on regional-level issues, including those associated with the ownership patterns and mineral rights of energy resources [8–11]. Additionally, authors have recently highlighted the need to address power asymmetries and structural inequalities in the transition to low-carbon energy systems, focusing on gender and social equity, cost-efficient energy supplies, distribution, and regional access to resources [12–15]. While gaps remain, these advancements are essential for developing more comprehensive and equitable regional wealth policy decisions.

Comprehensive wealth is a key indicator of economic sustainability and is critical in evaluating policy and sustainable development initiatives, particularly in ERRs. Here, wealth is defined as the social value of an economy's capital assets as defined by the International Human Dimensions Programme and the United Nations Environment Programme [16]. Wealth is arguably a more accurate measure of society's economic progress and well-being than gross domestic product (GDP), as it addresses many of the challenges associated with using GDP as an indicator of economic growth. For example, gross domestic product (GDP) is a key measure of a country's economic performance, calculated as the sum of final consumption, gross capital formation, and net exports [17]. It is often used as a proxy for economic growth, but its accuracy has been questioned [18,19]. Per capita GDP, which divides a country's GDP by its population, is a measure of average economic output per person [20]. It is influenced by factors such as literacy rate, unemployment rate, and investment in research and development [21]. The relationship between GDP and population growth is complex, with demographic changes impacting economic growth [22]. Conversely, wealth, when considered alongside GDP metrics, can offer a more comprehensive view of economic wellbeing. It accounts for the accumulation of assets and resources among individuals and can identify disparities in wealth distribution, providing a more nuanced understanding of a society's economic health and the wellbeing of its citizens [23,24]. Wealth is, therefore, a reasonable index for economic sustainability, and wealth estimation is increasingly used for policy development and evaluation at the national and regional levels because these estimates provide critical information about economic efficiencies and spatial inequities. Inclusive wealth is a crucial indicator of financial sustainability and is essential in evaluating policy and sustainable development initiatives [16]. Unfortunately, at present, there is no agreed-upon macroeconomic indicator of sustainability. However, indices of a country's change in wealth per capita over time may assist in identifying an appropriate indicator [25], and advances made at the local-to-regional levels may help in that endeavor. In addition, inclusive wealth enables an integrated coupling of ecological and socioeconomic systems to be assessed and for wealth sustainability to be examined over time. In this manner, wealth sustainability can be evaluated, and critical resources can be better constrained, or substitutions made. Multiple researchers have investigated the role of wealth in achieving sustainable economic development [26–28], and others have addressed various aspects of wealth creation, measurement, and place- and people-based wealth [29,30]. Despite this progress, the ability to develop, obtain, and organize disparate data sources to generate valuable information and knowledge for sustainable wealth-related policymaking is lacking.

The objectives of this article are to (a) provide background on select concepts of energy-rich regions (ERRs) and wealth as a critical indicator of sustainable development, to (b) present potential paths forward for the acquisition and development of knowledge bases for the development of such regions, and to (c) present the areas of growth necessary to advance model predictive confidence over time to improve decision making using wealth as the key indicator of regional sustainability. The objectives of this article are not to provide a comprehensive literature review or consider all potential perspectives but rather to present select opportunities to develop regional wealth knowledge bases and models to help identify ways forward that may assist assessment and policymaking for wealth-based regional sustainability. Thus, while the article may delve into practical methodologies or approaches, the overarching goal was to provoke critical thinking, stimulate discussion, and provide a roadmap and an inroad for further exploration. It is anticipated that the increased awareness generated through this article will mobilize assistance and generate new information that will strengthen this emergent area of research to intensify regional wealth sustainability for future generations.

1.2. Energy-Rich Regions, Wealth, and Sustainable Futures

Energy-rich regions (ERRs) are very diverse and are located in clusters across the globe. Collectively, they play a crucial role in the global economy. In 2014, the International Energy Agency estimated that approximately USD 44 trillion in new investment would be needed by 2040 to ensure an adequate energy supply to meet the world's growing demand [31,32]. According to the IEA, a significant portion of the investment needed for the global energy infrastructure will continue to be attracted to regions rich in fossil fuels such as oil, gas, and coal. The report further highlights that, while renewable energy sources are expected to increase rapidly, fossil fuels will continue to significantly meet global energy demand in the coming decades. It is worth noting that exploiting high-value energy (e.g., coal, oil, and gas) resources has played an essential role in developing energy-rich regions (ERRs). Indeed, many of these regions depend primarily on extracting exhaustible resources for economic wellbeing.

There is extensive literature on the development of energy-rich economies, particularly those in the developing world. However, most of the literature focuses on national economies [3,8,33–40], economic performance and resource loss [41,42], green national accounts, and properly valuing resource depletion [43–45]. However, while there are several published national-level studies, analyses of these economies at a regional scale are lacking. Ultimately, ERRs may exist at different growth and resource exploitation stages. Stated differently, at any given time and location, an ERR may be at a pre-resource, takeoff (transition to resource exploitation), maturity (resource depletion plateau), transition to post-resource stage, and post-resource stage; see Figure 1 [46]. The most crucial feature of regions rich in oil, gas, and coal is that these are exhaustible (i.e., finite) resources. The limited resources imply that such regions cannot consider resource revenues a permanent income stream over the long term. They must translate exhaustible natural resource capital into reproducible capital for economic and environmental sustainability [40,46,47]. Figure 1 briefly illustrates that exploiting (energy) resources significantly influences regional economic growth through predictable stages. In the image of Rostow's theory [48], a five-step model is shown for energy-based regions. In this example, the energy sector may have weak initial ties to other regional industries. Upon exploration, a surge in capital investment occurs, enabling infrastructure development and skilled labor influx. This phase marks a transition from pre-resource to intensive resource-based development. Investments peak, leading to maximum resource extraction capacity. A prolonged maturity stage ensues, sustaining production until reaching a plateau, which can last decades based on reserve size and extraction levels. It is a critical phase for returns on earlier investments and the transformation of resources into lasting capital for sustained growth post depletion. Post-peak, regional outcomes vary during a transition based on institutional quality, diversification, and successful resource-to-capital conversion. A successful accumulation of reproducible capital leads to sustained post-resource production. Diversification shifts the focus away from being solely an energy-rich region, integrating it into broader markets [46,48,49].

A central challenge in achieving sustainability is pursuing an equitable balance between the use and preservation, or conservation, of resources for present and future generations [1,2]. Solow [1] was among the pioneers who formally analyzed intergenerational equity issues related to exhaustible resources. Hartwick [2] noted that investing the entire economic rent from an exhaustible resource into reproducible capital is necessary to ensure intergenerational equity (i.e., the constant flow of consumption over time). Solow [50] showed that Hartwick's rule can be interpreted as holding a total stock of capital constant over time as a condition for intergenerational equity. More recent work has built on the previous results of Solow [1] and Hartwick [2] and others and linked investing exhaustible resource rents to growth in a model of optimal savings [51]. Ultimately, it is noted repeatedly in the primary literature that energy-rich economies should maintain a non-decreasing stock of total capital stock and be able to diversify their capital base to compensate for the ongoing depletion of exhaustible resources. With diversification in mind, recent World Bank studies suggest a broad, integrated framework for measuring wealth embodied in natural, physical, and human capital forms. This framework could provide a complete understanding of what may be sustainable or unsustainable development in a changing economy [25,52]. With these efforts, sustainable development has become both more comprehensive and quantitative. The World Bank defines sustainable development as *managing a portfolio of assets to preserve and enhance the opportunities people face* [52]. Assets in this definition include physical capital, also called produced capital, natural capital, and intangible capital, which includes human capital and the quality of formal and informal institutions [8,25,30,49]. The condition, therefore, for achieving sustainable development is that the value of these assets continues to grow over time, or that they at least do not decrease in value.

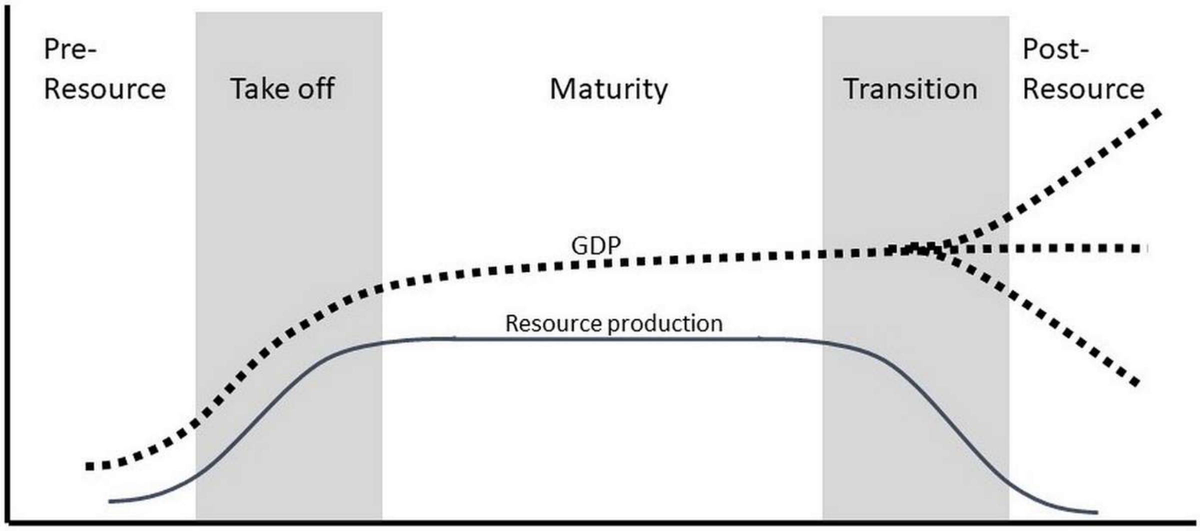

Figure 1. Stages of resource depletion and regional growth. Figure used with permission from Ghadimi [46]. The horizontal axis is time, and the vertical axis is quantity.

The constancy of total capital stock and the World Bank's notion of development as a "process of portfolio management" provide a broad framework to study economic development and conduct asset-based planning in resource-rich regions and communities, mainly where the most valuable assets are exhaustible natural resources [25,52]. In the general sense of intangible capital, sustainable development in such areas depends on managing finite resources and transforming natural capital into reproducible physical and human capital. Tracking the interplay of these three forms of capital over time provides a systematic framework for development planning in resource-rich regions. However, achieving these goals is under-exploited in the literature, which provides impetus for future investigations and advancements. Figure 2 illustrates the distinct phases involving the stocks of exhaustible natural capital (N), reproducible physical capital (K), and human capital (H). The critical factor determining the economic sustainability and success of development within an energy-rich region (ERR) is the conversion of exhaustible resources into reproducible capital. These growth stages apply to existing ERRs found across advanced economies and developing nations, encompassing various stages of resource utilization and capital transformation that influence their economic trajectories and sustainability. The outcome of converting exhaustible into reproducible capital, such that the total capital stock remains non-decreasing, determines the economic performance and sustainability of development in an ERR [46].

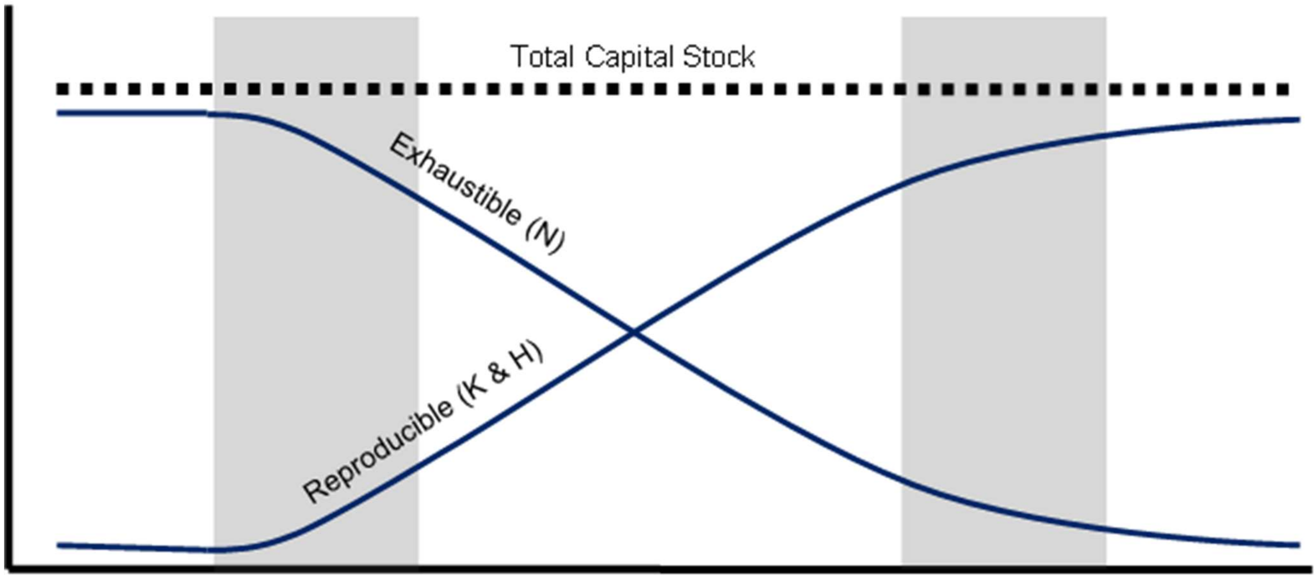

Figure 2. Stages of capital stock conversion. Used with permission from Ghadimi [46]. The horizontal axis is time, and the vertical axis is quantity.

2. Developing Sustainable Wealth

Sustainable wealth refers to the creation and maintenance of wealth in a way that is economically, socially, and environmentally sustainable [25,46,53]. Areas of development necessary for achieving sustainable wealth may include, but are not limited to, areas of (a) economic, (b) social, (c) financial, and (d) community development. Economic development should always include creating and maintaining economic growth that does not deplete natural resources or harm the environment [9,43,44,54]. Social sustainability involves ensuring that economic growth benefits all members of society rather than just a select few [55]. Environmental sustainability consists of protecting natural resources and ecosystems and reducing the negative impact of human activities on the environment [56]. Financial sustainability means ensuring the stability and security of financial systems and protecting individuals and businesses from financial risks [57]. Community development involves investing in local communities and promoting their economic, social, and environmental wellbeing. Environmental sustainability is an essential and largely undiscovered aspect of developing these areas. Previous authors have identified the importance of sustainable economic development in sustaining environmental resources and encouraging green growth [58–62]. However, the progress in integrating environmental sustainability into development areas has been relatively slow. Hence, the impetus for the current call (need) for investigation. Innovations in any of these areas should include promoting and investing in new technologies and business models that can help reduce environmental impact and increase social benefits [63]. All these areas (and likely others) are interrelated and mutually reinforce each other, requiring systemic, integrative problem-solving approaches.

2.1. Developing Regional Wealth Knowledge Bases

An ongoing challenge for sustainable regional wealth policymaking relates to information (data) acquisition and organization. The idealized knowledge base development process presented in the following text may assist in actualizing (developing and implementing) regional wealth knowledge information databases. Conceivably, the development of regional wealth knowledge bases can involve several processes, including those shown in Figure 3. This process is not significantly different from other disciplines' established knowledge acquisition methods [64–68]. Here, we present a conceptual framework for acquiring regional wealth information to develop databases for future model implementation. As shown in Figure 3, the process begins with data collection (1), which requires the gathering of information about the economic, social, and environmental conditions of a location of interest. These data may include information on population demographics, economic activity, natural resources, and environmental conditions. Analyses (2) include interrogation of the data to identify relationships, strengths, weaknesses, needs for additional information, and potential opportunities for growth and development. Stakeholder engagement (3) should include engaging with the local community, government, businesses, and other stakeholders to gather their input, feedback, ideas, and buy-in regarding the creation of sustainable regional wealth. Knowledge sharing (4) includes sharing findings and recommendations from the data analysis and stakeholder engagement with the local community, government, businesses, and other stakeholders. Knowledge-sharing activities can be accomplished through workshops, conferences, and other events. Implementation (5) involves acting on recommendations from the investigation and ideas generated through data analysis, stakeholder engagement, and knowledge sharing. These activities can include developing new policies, programs, and initiatives to promote sustainable wealth creation in the region. Finally, monitoring and evaluation (6) should consist of monitoring the implementation progress and evaluating the impact of the policies, programs, and initiatives on regional wealth creation. This process is similar to ecosystem restoration planning and implementation processes, aided via conceptual frameworks. These frameworks typically follow a conceptual diagram approach similar to that presented in Figure 3, illustrating the relationships between key drivers, stressors, ecological impacts, and management responses [68–70]. Such diagrams can help ensure appropriate management actions to address critical problems, reduce impacts, and lead to sustained restoration.

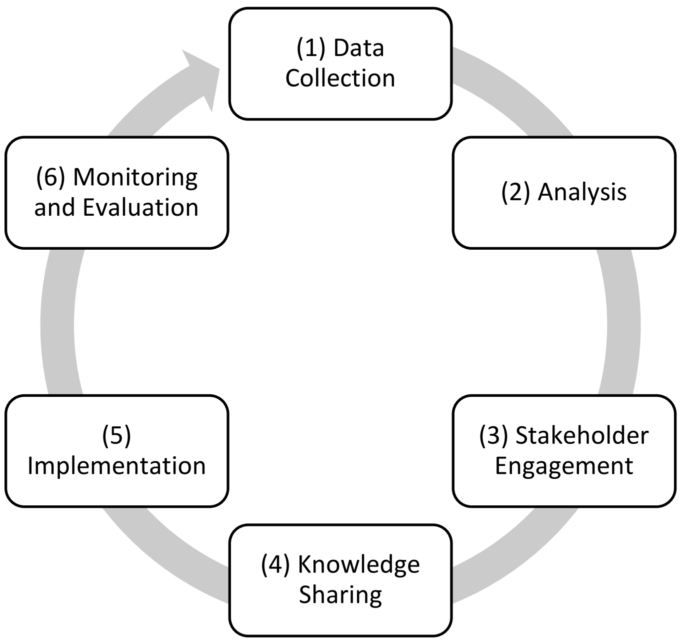

Figure 3. A hypothetical process to develop knowledge bases for sustainable wealth.

It is worth noting that, while perhaps appearing so in Figure 3, these processes are not linear, and it is essential to have continuous feedback loops and adjustments to adapt to changing circumstances. Thus, the techniques described and diagrammed in Figure 3 imply an iterative process. Additionally, it is worth noting that many similar approaches could be used for sustainable wealth database development. Managers and policymakers adapt many such plans, including those used by the Natural Resource Conservation Service (NRCS) [64,65,68]. Finally, the outcomes of these efforts can be improved in the long term through effective outreach and stakeholder meetings, as indicated in step three (3) in Figure 3, that result in stakeholder buy-in [71,72]. There is, however, an ongoing need for studies focused on the lifecycle of these processes, and studies may include the econometric benefits (or detriments) at all stages of development. Ultimately, supplying appropriate scientific and socioeconomic data is critical for developing models to provide near-real-time information to stakeholders, simultaneously building confidence, engagement, buy-in, and tangible program outcomes [71].

2.2. Developing Regional Wealth Knowledge Bases: Integrating Geoscience

Conceivably, a contemporary regional wealth estimation and evaluation model should integrate geoscience and geospatial technologies, including (but not limited to) remote sensing and drone technologies, to estimate the magnitude of regional wealth embodied in the capital forms and uses of various economic criteria to assign a dollar value to different asset forms. Such a model should also be adaptive, dynamic, and process-based [73], providing dynamic integrated perspectives of change over time and a predictive model to assess future scenarios [74]. There are typically many steps in the process of model development. A general (hypothetical) example of model development for a regional wealth knowledge model is provided in Figure 4. This diagram's intent is not to be all-inclusive or exhaustive in content. As needs vary by geographic location, so should regional wealth model development and deployment processes. However, the process diagram in Figure 4 may assist planners in initiating the process in their site(s) of interest.

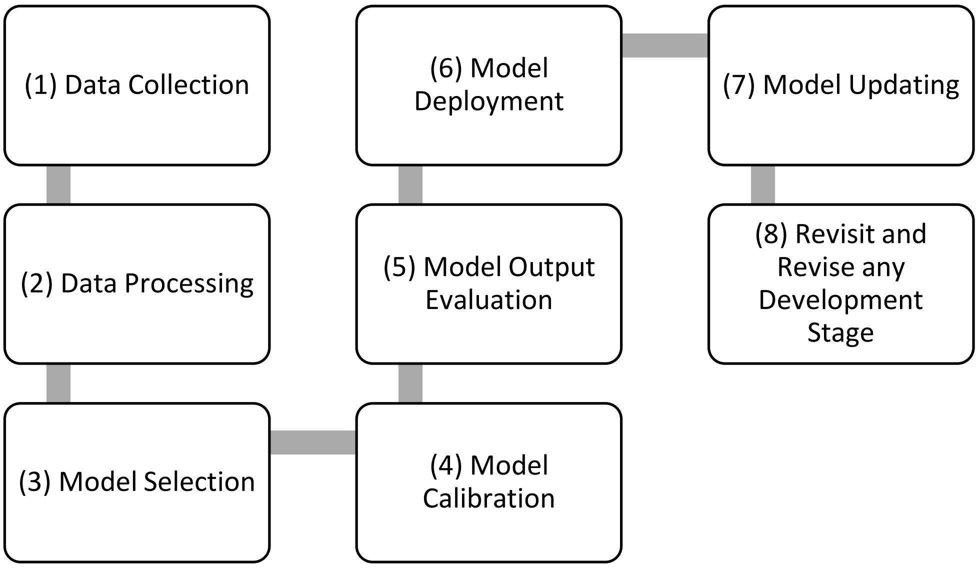

Figure 4. Hypothetical model development steps for a regional wealth knowledge model.

Recognizing that model development processes can vary (if not depart) widely from Figure 4, the process of developing most regional wealth knowledge models will almost always include several steps that should include: (1) data collection, during which data are gathered on various economic indicators such as gross domestic product (GDP), income, employment, and poverty rates for the region of interest; (2) data preprocessing that includes the cleaning and preparation of data for analysis through removing errors, handling missing values, and transforming variables as necessary; (3) model selection, which should include the selection of an appropriate model for the data, such as linear regression or a neural network, based on the type of data, the research questions asked, and desired model outcomes; (4) model training, sometimes called calibration, in which the model is initially forced using the preprocessed data. Calibration usually involves adjusting the model's parameters to minimize the error between the predicted and actual (observed) values. (5) Model evaluation requires that the performance of the trained model be evaluated using metrics such as accuracy, precision, and recall. (6) Model deployment occurs when the calibrated model is sufficiently prepared for real-world, situational use in the production environment. Step seven (7) should include model maintenance, in which the model is regularly monitored and updated, as needed, with new information. Finally, step eight (8) implies an iterative, non-linear process that may include revisiting any development stage requiring revision, thereby improving modeling outputs. This process is dissimilar to other disciplines' techniques [64,65,75].

2.3. Validating Regional Wealth Models Using Pilot (Case) Studies

Conducting pilot and case studies to validate regional wealth models is critical in developing and maintaining accurate and reliable models of wealth that are adaptable as new information becomes available and necessitates change [76–78]. Multiple authors have identified several steps necessary for model validation studies [79–83]. Those steps may include (but are not limited to) defining the scope and objectives of the pilot study, selecting the appropriate data sources, designing the study methodology, collecting and analyzing data, and evaluating the results. This process is similar to the procedures presented in the preceding sections. To define the scope and objectives of a pilot or case study, model validation key variables should be identified, including indicators that will be used to measure regional wealth and the geographic area that is to be studied. The objectives should be specific and measurable, and they should be aligned with the overall goals of the project. Next, data sources that meet the project's objectives should be selected. Data sources may include (but not be limited to) administrative records, surveys, and other data sources relevant to the wealth variables being studied. Data sources should be as comprehensive and representative as possible of the studied population and accessible and reliable [84–87]. Once data sources are identified, the study methods should be detailed. Based on the pilot study results, the plans should be flexible and adaptable to allow for necessary changes.

It is worth restating that data collection is critical in the pilot study process. The data should be collected systematically and consistently, using standardized procedures and instruments. Figures 3 and 4 and the related text emphasize this point. Data analysis should involve regression, factor analysis, or other appropriate statistical techniques to identify relationships between wealth variables and other factors [87–89]. Finally, the results should be critically evaluated to determine the validity of the wealth model outputs. This necessitates comparing the results of the pilot study to the anticipated outcomes and assessing the reliability and accuracy of the data. The results should also be compared with those from similar studies to determine whether the model is generalizable (transferable) to other regions or populations. If the pilot study results are unsatisfactory, then the model may need to be refined or modified. Model modifications may require the collection of additional data, adjustments to the study methodology, or changing the model. The pilot study should be repeated until the results are consistent and reliable and the model is validated [64,76,78]. Once the wealth model has been validated, it can be used (confidently) to supply accurate predictions about regional wealth and to inform policy decisions and resource allocation. The results of a pilot study can also be used to guide future studies and improve the wealth model's accuracy and robustness over time [90,91]. With careful planning and execution, pilot studies can provide valuable insights into regional wealth patterns and trends and help inform policy decisions and resource allocation.

2.4. Dissemination of Regional Wealth Model Results

Sharing results from regional wealth models is essential in ensuring that the results are widely understood and effectively applied. It is also a critical step in the iterative process to improve future model outputs and to generate stakeholder buy-in (Figures 3 and 4). The most appropriate methods of sharing RWM results depend on the target audience, the results' purpose, and the complexity of the data [92,93]. However, several general principles can be followed to ensure the effective communication of the results. For example, it is essential to understand the target audience and their needs. The audience may include policymakers, community leaders, business leaders, researchers, and the public. Understanding the target audience can help to determine the most effective format and level of detail for sharing the results [94–97]. For example, policymakers may prefer a concise executive summary highlighting key findings, while researchers may require more detailed technical reports that include data and methodologies. The purpose of the results must also be determined. This may involve informing policy decisions, guiding resource allocation, or increasing public understanding of regional wealth patterns and trends. Understanding the purpose of the results can help to determine the most effective way to communicate the results to the target audience and to emphasize the most important findings [93,97]. Visual aids such as graphs, tables, and maps can help communicate complex information in an accessible and engaging manner. It is also essential to be transparent about the limitations and uncertainties of the results. This may include explaining the sources of data and the methods used to analyze the data and highlighting any limitations or assumptions that may have influenced the results. Being transparent about the results' limitations and uncertainties can help build trust with the target audience [71] and encourage further discussion and analysis of the results.

Another critical characteristic of the effective dissemination of results is the inclusion of context for the findings. This information may include explaining the background and context of the wealth model and highlighting any key trends or patterns relevant to the results. Providing context can help the target audience understand the results' significance and see how the results fit into the broader picture of regional wealth patterns and trends. Finally, engaging the target audience and encouraging feedback and discussion regarding the results are essential. Stakeholder engagement may include hosting public presentations, providing opportunities for feedback and discussion through online forums, or engaging with key stakeholders to discuss the implications of the results. Engaging the target audience can help to build support for the wealth model and encourage further analysis and use of the results [94–97]. Ultimately, understanding the target audience, determining the purpose of the results, choosing the most appropriate format, using clear and concise language, being transparent about the limitations and uncertainties of the results, providing context for the findings, and engaging the target audience will result in the most effective dissemination and, therefore, usefulness of results from regional wealth models.

3. Necessary Innovations and Advancements

While there has been some interest in examining wealth estimation at the regional and community levels [29,98,99], national-level analyses tend to be predominant. However, wealth estimation is central to regional policy and evaluation because these estimates provide critical information about smaller-scale economic efficiencies and spatial inequalities.

The information presented in this article builds on previous research results exploring how the significant components of regional wealth could be estimated using geospatial technologies and associated spatial databases [47,49]. These technologies should be expanded to include geospatial websites, crowdsourced geographic information, and sensor-carrying drones, which may require the refinement of current quantification and valuation procedures. Many studies have demonstrated the potential of geospatial technologies, spatial datasets, and crowdsourced geographic information in wealth estimation at the regional and community levels. Ledesma et al. [100] and Tingzon et al. [101] highlighted the effectiveness of combining machine learning with social media data, satellite imagery, and volunteered geographic information for poverty mapping and wealth estimation. Dong et al. [102] and Arsanjani [103] further emphasized the role of remote sensing and geospatial technologies in understanding land systems and public health, respectively. The use of sensor-carrying drones for data collection was presented by Harris [104] and Elwood [105], who explored the impact of neogeography and volunteered geographic information on geospatial technologies. A general framework for calculating regional capital stock drawing on data generation, data handling, and spatial analytical modeling of GIS and remote sensing is presented in Figure 5.

As shown in Figure 5, the major components of each capital type and corresponding data items and sources are listed in a spatial metadata database. The conversion methodology, consisting of a detailed estimation and valuation procedure for each capital type, uses the metadata to produce an estimate of the physical (K), natural (N), and human (H) capital forms for each desired spatial unit. This information can then be consumed and interrogated via a regional wealth model (RWM) to suit the needs of planners in the desired location [47,49]. An inventory would be developed, including the available spatial data for the state, county, and finer spatial units, and categorized within the context of physical, natural, and human capital forms. For example, for physical capital, the focus may be on indicators comprising buildings, residential and non-residential, and infrastructure, including transportation, communication, and water and energy delivery systems. For natural capital, the focus may be on fossil energy resources (oil, coal, shale gas), mineral resources, and other significant contributors to national and global wealth and ecosystem services. Human capital indicators may include educational attainment, demographic structure, skills and training levels, and other variables and attributes that may be important for a given location [46,47,49].

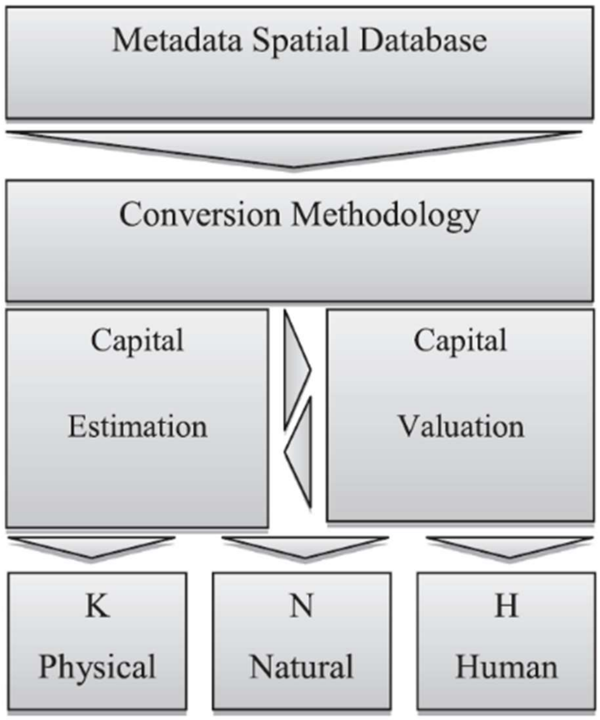

Figure 5. Example of a wealth evaluation model (WEM). Used with permission from Ghadimi, Harris, and Warner [47].

Numerous foundational advancements are needed to advance regional wealth model application and predictive confidence. We do not intend to include them all here, as many may involve placed-based differences [106], geographical distinctions [107], or user-preferential differences. Regardless of perspective, it is difficult to argue against the advancements needed to improve the usefulness and confidence of RWMs. For example, non-financial metrics need to be integrated, including, but not limited to, social and environmental sustainability indicators [54]. Including these types of information will provide a more comprehensive and accurate characterization of a region's wealth, with more than traditional financial metrics. For example, there is a need to develop more advanced methods for the economic valuation of intangible assets, such as human capital, cultural heritage, and natural resources [108–110]. These assets can have significant value to a region but are often overlooked in traditional financial metrics. For example, human capital, in the form of a highly educated and skilled workforce, can significantly attract new investment and promote economic growth but is often difficult to measure and quantify [111]. Another critical innovation needed in developing RWMs is greater collaboration and data sharing between government agencies, businesses, and communities. Accurate and comprehensive data are crucial for ensuring the validity and relevance of RWMs but can often be challenging to obtain. By fostering greater collaboration and data sharing, regions can more effectively collect the data they need to accurately estimate collective and sustainable wealth [112–114]. This collaborative approach can also help ensure transparency and accountability using these models, as stakeholders may better understand the data and methods used (e.g., Figure 3). Similarly, including local stakeholders and stakeholder groups in the development of these models can help increase the stakeholder buy-in [71,115] and support for the models, as they may better understand how the models were developed and what they are meant to achieve.

Finally, advances in artificial intelligence (AI) are needed to improve RWM development. Previous studies explored the use of artificial intelligence in regional wealth model development. For example, Chernov et al. [116] and Li et al. [117] highlighted the potential of AI in scenario modeling and financial efficiency analysis, respectively. Ma [118] further demonstrated the application of AI in analyzing the impact of environmental pollution on income and in clustering and ranking regions based on economic indicators. Kacprzyk [119] and Ginis et al. [120] proposed using AI in solving regional development problems and in cognitive and simulation modeling of regional economic systems. Several artificial intelligence models have been proposed to improve regional wealth model development. For example, machine learning and big data analytics in scenario modeling and economic potential analysis have been recommended [116]. Other authors have suggested using cognitive informatics and simulation modeling for human-centric systems and sustainable development [119,120], while others proposed feature selection and ensemble decision frameworks for GDP prediction and financial development index construction [108,117]. Ultimately, while progress has been made, there is much work to do. Advances are required (there are likely others not noted here) that will (1) reduce limitations in high-resolution spatial and temporal data, (2) resolve the typical lack of robustness of AI solutions that use heterogeneous, noisy, and variable-quality data, (3) address challenges in generalizing AI models in critical areas (i.e., reducing complex datasets to organized comprehensible model forcings), (4) clarify best approaches in AI and machine learning (ML) methods for regional wealth models, and (5) advance what may currently be a limited integration of domain knowledge and models in AI/ML. While high-resolution datasets are essential for the best econometric decisions, datasets are typically only available at coarse resolution. This is due to the lack of methods that combine coarse or mid-resolution data (e.g., satellite imagery) with high-resolution sensor data (e.g., aerial or ground sensors). For example, multitasking and multimodal learning are standard ML tools for heterogeneous data [121–124]. However, current approaches cannot navigate disparate spatial or temporal resolutions and struggle with imbalance across different modalities (e.g., the sparse availability of high-resolution data).

Similarly, there is a significant gap in understanding how to integrate multiple model modalities, mainly when they occur at different spatial, temporal, and spectral resolutions, and the data are of poor quality. AI models must, therefore, become more adaptable to unusual, unseen, and unconventional data. Furthermore, AI models must be resilient and robust in response to perturbations. Several approaches in statistical learning theory (e.g., hypothesis-space complexity) characterize the generalization gap in deep learning models. However, state-of-the-art results can achieve complexities with exponential dependence on depth [75,125,126] or linear dependence on the number of parameters [127]. Other approaches, such as stability-based [128–130] or robustness-based [131] approaches, require some knowledge a priori. Ultimately, integrating technology, such as artificial intelligence and machine learning, can be critical in automating data collection and analysis, gathering the data needed to measure regional wealth more efficiently and accurately. By leveraging these technologies, regions can more quickly and efficiently process large numbers of data, making it possible to assess their wealth and make more informed decisions about managing and investing their resources, with greater confidence in the outcomes.

4. Synthesis and Implications

This article includes a conceptual development framework based on the established theoretical and multidisciplinary literature and a systematic regional knowledge base as a broad context for applied quantitative and qualitative development analyses of energy-rich regions. Our approach was to include generalized methodologies to contribute to the broader conceptual landscape of the subject area to facilitate critical thinking, stimulate discussions, and provide an inroad for readers wishing to learn more. A discussion of the wealth and sustainable wealth of energy-rich regions is presented. We offer workflow methods for developing regional wealth knowledge bases and the development of regional wealth models. Several vital innovations are needed in order to develop regional wealth models that can effectively measure and manage regional wealth. We do not intend to include them all here, as many may involve placed-based differences or preferential-user differences. General advancements are needed, however, to improve the usefulness of, and confidence in, RWMs. For example, non-financial metrics need to be integrated, including, but not limited to, social and environmental sustainability indicators. For example, Fullerton [132] noted the importance of reaching beyond sustainability to consider restoration and regeneration. Indeed, the regenerative capitalism concept advocated by Fullerton [132] emphasizes the importance of restoration and regeneration in the economy. This idea is particularly relevant in the circular economy context, where restoration is a well-defined concept with widespread application [133]. However, while symbolic, the concept of regeneration may not be as practically applicable [133]. Despite this, the circular economy can be crucial in boosting land restoration and achieving sustainable development goals [134]. In the agricultural sector, regenerative agriculture, which focuses on building soil health and increasing biodiversity, is a crucial aspect of restoration and regeneration [135]. Similarly, natural regeneration in large-scale forest and landscape restoration can contribute to achieving social, economic, and environmental benefits [136]. These studies underscore the importance of restoration and regeneration in regenerative capitalism, as they can contribute to environmental sustainability, economic recovery, and social welfare.

Another critical innovation needed in developing RWMs is greater collaboration and data sharing between government agencies, businesses, and communities. Artificial intelligence (AI) must be used to advance the development of regional wealth models (RWMs) by automating data collection and analysis. To maximize the benefits of AI in this context, models must be adaptable to unusual, unseen, and unconventional information and more resilient and robust in response to perturbations. Advancements in machine learning (ML) technologies can be essential, enabling RWMs to automate and interrogate complex datasets and generate more accurate predictions of future trends. In addition to AI, another critical factor to consider when evaluating the sustainability and equity of energy-rich regions is the ownership of capital forms. In many such regions, natural resources are owned and controlled by a relatively small group of individuals or entities, leading to significant wealth concentration and inequality. Small-group control can negatively affect long-term sustainable development and social and political stability. As such, any analysis of regional wealth in energy-rich regions should also integrate the distribution of ownership of natural, physical, and human/intangible capital and explore policy interventions that can promote more significant equity and social justice.

5. Conclusions

The workflow methods described in this article build on the literature related to the multifaceted development field of energy-rich economies, assuming that ERRs will receive substantial investments in the coming decades. Fossil fuels will continue to be vital in meeting the world's energy needs over the next few decades, and ERRs will continue to attract significant new investments. As a result, investments in ERRs will alter the capital composition in these regions, and the outcome could profoundly impact sustainable development on the regional, national, and even global scales. To better understand the development processes of these economies, case studies of ERRs with different economic structures, reserve sizes, and positions on the planned market spectrum experiencing other political systems and growth stages could provide invaluable insights into the development processes of these economies. Case (pilot) studies and comparative analyses can facilitate exchanges of experiences for ERRs with varying economic structures, stages of development, and resource life and provide a broad perspective on the salient features of development in ERRs around the globe. These qualitative studies can result in important regional, national, and global policy lessons. The broader context of energy-rich economy development suggested in this paper can also be used to derive stylized facts and development patterns that can be useful in understanding and addressing the sustainability of ERRs. However, supplying appropriate scientific and socioeconomic data to develop knowledge databases and models to provide near-real-time information about regional wealth is critical. Increased awareness will mobilize assistance and generate new information that will strengthen this emergent area of research and intensify regional wealth sustainability for future generations.

Finally, the workflow methods presented in this article emphasize the need for a balanced approach to sustainable development in ERRs, using regional wealth as a key indicator and adequately accounting for the requirements for wealth sustainability during the transition to the post-resource stage. Policymakers can gain valuable insights that inform regional, national, and global policies by conducting case studies. By providing accurate data and models, leaders can facilitate the exchange of knowledge and strengthen the sustainability of regional wealth for future generations. This approach can help create a more sustainable future for energy-rich regions and their inhabitants.

Author Contributions: Conceptualization, J.A.H. and H.G.; methodology, J.A.H. and H.G.; software, J.A.H.; investigation, J.A.H. and H.G.; resources, J.A.H.; writing—original draft preparation, J.A.H.; writing—review and editing, J.A.H. and H.G.; visualization, J.A.H. and H.G.; supervision, J.A.H.; project administration, J.A.H.; funding acquisition, J.A.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the USDA National Institute of Food and Agriculture, Hatch project accession number 1011536, McIntire Stennis accession number 7003934, and the West Virginia Agricultural and Forestry Experiment Station. Additional funding was provided by the USDA Natural Resources Conservation Service, Soil and Water Conservation, Environmental Quality Incentives, Program No: 68-3D47-18-005, the Environmental Protection Agency, Grant No. D-96362401-0, and a portion of this research was supported by Agriculture and Food Research Initiative Competitive, Grant No. 2020-68012-31881 from the USDA National Institute of Food and Agriculture. The results presented may not reflect the sponsors' views, and no official endorsement should be inferred. The funders had no role in the study design, data collection and analysis, the decision to publish, or the preparation of the manuscript.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The author appreciates the feedback of anonymous reviewers, whose constructive comments improved the article.

Conflicts of Interest: The authors declare no conflict of interest.

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