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Systems Energodynamic Approach as an Instrument of Increasing Efficiency of Engineering Developments

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I. N. Dorokhov [α] & Doc. V. Etkin [σ]

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I. Introduction

The current state of natural science and theoretical physics clearly demonstrates what can be referred to as "epistemological inversion". As R. Feynman figuratively expressed it, it became preferable to "guess equations without paying attention to physical models or physical explanation" of a particular phenomenon. Speculative models and postulates are increasingly replacing experimental facts as the basis for the modern edifice of science. Scientists are no longer burdened by the fact that their theories do not clarify reality, they no longer aim to understand cause and effect relationships. Phenomena explanation is no longer the primary function of science. Therefore, there are more and more statements about the modern crisis of theoretical physics.

The bifurcation of natural science, which occurred between the 19th and 20th centuries, led to the emergence of new branches of classical science. The first is the special and general theory of relativity and quantum mechanics (QM). The secondis general systems theory and computer science. The third is the transformation of classical (equilibrium) thermodynamics into the thermodynamics of irreversible processes and energodynamics. At present, the results of mutually complementary development of these three branches are obvious. The first one led to the appearance of the atomic weapons, ITER, TOKAMAK, CERN. The second one led to the personalization of computers, global informatization and digitalization. The third one led to the personalization of energy consumption, which is struggling to break through.

A. Einstein believed that thermodynamics was a science of principles, and its conclusions would never be refuted, and this idea corresponds to the fact that thermodynamics is the recognized "queen of sciences." The uniqueness of thermodynamics as a systems science is that its starting points naturally lead to the existence of hidden energy carriers, such as electric charge, the nature of which is still not clear, or ether, previously excluded from consideration. The energdynamic concept of a material energy carrier and the generalized law of conservation of energy open up the possibility of quantitatively assessing the result of the transformation of energy from one form to another in conditions of incomplete information about its mechanism. This is where the key to understanding and practical use of the vast factual material accumulated in natural science lies, which cannot be explained by modern science [1]. The purpose of this article is to show a real way to overcome the crisis of theoretical physics by transforming classical thermodynamics into a theory of principles based on a systems approach.

II. Methodological Features of the Systems Energodynamic Approach

It refers to a comprehensive methodology, which involves combining systems analysis with the highest level of thermodynamics — energodynamics, which expands it to any non-static processes and any forms of energy. The systems approach uses the concept of a system as a set of elements, which has integrity due to system-forming relationships. The property of integrity is reflected in the philosophical thesis of nonadditivity of the whole, which was recognized as early as Aristotle and Plato: the whole is greater than the sum of its parts. Integrity combines the properties of structuredness, self-organization and emergence of the system. Structuredness manifests itself in the hierarchical structure of the system, self-organization — in the occurrence and development of structures in an initially homogeneous environment, emergence — in the spontaneous occurrence of new properties in the system. Gravity, movement,

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emergence of new elements and chemical compounds, and so on are manifestations of these properties in nature. [2-11].

The universal characteristic of an energodynamic system is energy, which is the most general function of its state. Its derivatives determine all other properties of the system by independent arguments. Energy acts as a link between various processes occurring in a thermodynamic system — mechanical, thermal, chemical, electromagnetic, nuclear processes, etc. The basis of energodynamics is the law of conservation and transformation of energy, which has no limitations [12-18].

The analysis is of a deductive nature (from the general to the particular) and relies solely on experience-validated data on natural phenomena, i.e., phenomenology. The systems approach does not exclude from consideration those internal (hidden from the observer) system-forming relationships, through which the system as a whole acquires new properties that its individual parts (elements) did not have and without which the system cannot function fully. Deductive analysis is more challenging for the researcher, yet it allows the results of inductive analysis to be critically evaluated (verified) and therefore brings it closer to reality. For instance, energodynamics does not exclude the study of internal (including dissipative) processes, that classical mechanics usually neglects, limiting itself to "conservative" systems. The discovery of the impossibility to restore the system-forming properties, which were lost when the system was split into volume or mass elements during its analysis, by further integration was "the most profound and the most fruitful that physics has experienced since the time of Newton" [19], according to A. Poincaré.

The energodynamic system is vaster than the mechanical system. Elements of a mechanical system are material points, and elements of an energodynamic system are real processes and their coordinates are material carriers of various forms of energy — the so-called energy carriers. Whereas in mechanics the coordinates of position and velocities of individual material points serve as generalized coordinates of the system state, in energodynamics the coordinates are numerical characteristics of material energy carriers Θ_i and displacements $\mathbf{R}_i$ of their centers in relation to equilibrium, characterizing the system as a whole. The energy U is an extensive characteristic of the system and is a single-valued function of the extensive energy coordinates $U = U(\Theta_i, \mathbf{R}_i)$. For example, in energodynamics, a mechanical process is characterized by mass and displacement of the center of mass, a thermal process is characterized by entropy and displacement of its center; a chemical process is characterized by the amount of a component and displacement of its center; an *electrodynamic* process is characterized by charge and displacement of its center, etc.

The presentation of mechanics in theoretical physics courses is based on the postulates of homogeneity and isotropy of space and homogeneity of time, as well as Lagrange's variational principle of least action, a special case of Gauss's principle of least constraint [20], which is more general. The authors [20] have admitted that space is not homogeneous and isotropic with respect to an arbitrary frame of reference. Thus, if a body does not interact with any other bodies, it does not mean that its various positions and orientations in space are mechanically equivalent. This non-equivalence is clearly manifested when it comes to spatially heterogeneous media, which are anisotropic since a number of properties depending on the gradients of any potentials varies in different directions.

The transition to the energy coordinates of the state (Θ_i, $\mathbf{R}_i$) supplemented by the axiom of process heterogeneity, leads inevitably to an absolute frame of reference [6]. The concept of an energodynamic system, being free from the postulates of homogeneity and isotropy of space and Galileo's principle of relativity, limited to linear and steady motion, is much broader than the concept of a mechanical system, thus, making the mechanical system a special case of an energodynamic system. For energodynamics, mechanics is an "equal" representative among all other, including non-mechanical forms of matter motions. With this view of mechanics, not only does it require a correction of all its laws, but it also provides a natural explanation of the principle of least constraint in mechanics mentioned above.

Being a consistently phenomenological theory, energodynamics relies on experience rather than on models of the mechanisms of natural processes. Its underlying principles are specified on the basis of experimental data on particular properties of the systems under study (including the so-called laws of Newton, Coulomb, Ampere, equations of condition, transfer, mass balance, charge, impulse, momentum, etc.) which are involved as additional single-valued conditions for the completion of the set of equations. Its equations are based on the formalism of differential and integral calculus and mathematical properties of the system energy as a characteristic function of a certain number of state variables reflecting the quantitative and qualitative aspects of the forms of motion under study. Therefore, the consequences of such a theory become fundamental truths within the applicability of single-valued conditions, whereas energodynamics itself becomes a "theory of principles" as Einstein put it [21].

It is known that all conservation laws were formulated for isolated systems. However, none of the fundamental disciplines can study such systems, since their conceptual system and mathematical apparatus are oriented to locally or globally homogeneous (internally equilibrium) macro- or micro-subjects, which have no internal processes, so that any changes in their state are due solely to the action of external forces and external energy exchange. A breakthrough in this direction was made by the thermodynamics of irreversible processes (TIP) [22, 23], which emerged in the first third of the 19th century following quantum mechanics (QM) and the theory of relativity (TR). It enriched the theoretical thought of the 20th century with a number of new principles of general physical nature and made it possible to study the kinetics of internal relaxation processes that occur alongside the processes of external energy exchange in all study subjects without exception.TIP became the third of the above-mentioned theories of a revolutionary nature that changed the image of physics of the 20th century, which was celebrated by awarding Nobel Prizes to L. Onsager and I. Prigozhin.

However, this theory was based on the principle of increasing entropy and therefore excludes from consideration the reversible component of real processes, which does not affect entropy. Meanwhile, the study of processes of useful transformation of energy was the main task of classical thermodynamics. The kinetics (power) of these processes is of primary interest to the engineer. There is a need to develop a unified theory of the rate of energy transfer and transformation, which would not exclude from consideration any (reversible or irreversible) component of real processes. Such a theory was proposed in the works of one of the authors of this paper and was called "thermokinetics" [13]. All its provisions were justified in a purely thermodynamic way (i.e., not involving hypotheses, postulates, modeling representations, and statistical-mechanical nature). Later it was generalized to the processes of transformation of any forms of energy and called "energodynamics" [14].

Unlike other fundamental disciplines, this theory considers isolated systems as the subject of study, which includes the entire complex of interacting (mutually moving) material subjects. Due to this, it is most consistent with both the systems approach and the deductive method of study (from the general to the particular) followed by classical thermodynamics [24]. Energodynamics is characterized by the refusal to use hypotheses and postulates in the foundations of the theory, idealization of systems and working bodies (contained in concepts such as "ideal gas", "equilibrium state", "reversible (quasi-static) process", etc.), as well as speculative models and ideas regarding the atomic and molecular mechanism of processes. Its special feature is the separation of the theoretical part, based solely on principles of general physical nature, from the applied part, using modeling representations, hypotheses and postulates. This allows it to preserve the main advantage of the thermodynamic method — the irreversible validity of its consequences within the limits of applicability of the initial paradigm of natural science. This property is also preserved when the single-valued conditions involved in the applied part of the theory are also reliably established.

Energodynamics is based on two principles: distinguishability of real processes and their counterdirectivity. The first one establishes a necessary and sufficient number of energy arguments as the most general function of the properties of the subject of study (i.e., system). This principle is proved "by contradiction" based on the theorem stating that the number of degrees of freedom of a system (i.e., the number of independent parameters uniquely determining its state) is equal to the number of independent (specific, qualitatively distinguishable and irreducible to others) processes occurring in it. This principle prevents "underdetermination" or "overdetermination" of a system, i.e., it attempts to describe their state by a missing or redundant number of variables, which is the most common cause of fallacy in a majority of theories. Among the latter are those theories where the concept of homogeneity is initially assumed, excluding relaxation processes and everything related to non-equilibrium processes from consideration.

The second principle establishes the fact of opposite direction of non-equilibrium processes, which is the reason for the appearance of new properties in the system. It is sufficient to represent the value of any extensive parameter of the system Θ_i (its mass M, entropy S, electric charge Θ_e, impulse **P**, its momentum **L**, etc.) by integrals of its local $\rho_i = d\Theta_i/dV_i$ and average density $\bar{\rho}_i = \Theta_i/V$ using the expression

$$\Theta_i = \int_V \rho_i dV = \int_V \bar{\rho}_i dV,$$

Hence the identity directly follows:

$$\int_V d(\rho_i - \bar{\rho}_i)/dt\, dV \equiv 0, \quad (1)$$

which is observed only if the sign of velocity of any process $d(\rho_i - \bar{\rho}_i)/dt$ is opposite at least in some elements of its volume dV, i.e., when these processes are counterdirected. Such counterdirectivity of processes has a general physical nature, i.e., there are always such processes among those occurring in spatially heterogeneous systems, which cause opposite changes of its properties like the process of wave formation. This is evidence of the existence of a natural polarization of nature in the most common sense of this term. It can be considered a physical justification for the law of unity and struggle of opposites. If the properties of an energodynamic system do not differ from the average, then no processes in such a system are impossible. The opposites arise only as a result of deviations from the average value of any properties of the system. Herein lies the emergent nature of the energodynamic system. This property is inherent in all natural phenomena in big and small forms from microto megaworld and serves as the basis of the universe. This property limits numerous fancies about the existence of matter and antimatter, particles and antiparticles, positive and negative energy, positive and negative charges, dark energy and dark matter, and so on and so forth. These two principles were sufficient to create a general theory for all fundamental disciplines, explained using unified concepts and terminology [14]. This approach was celebrated by winning the 1st World Science Championships in Dubai (August 2023) [2].

III. Heterogeneity Parameters of Real Processes and the law of Conservation and Transformation of Energy

For the first time, energodynamics made it possible to study internal processes in locally heterogeneous and isolated systems due to the introduction of missing heterogeneity parameters. These parameters reflect the processes of redistribution of energy carriers Θ_i over the volume of system V in heterogeneous systems, as a result, their densities ρ_i in different parts of the system change in the opposite ways. This leads to a deviation of the position of the center R_i of the value Θ_i from the equilibrium R_{io}(taken as a reference point), which are determined in a system of fixed volume V in a well-known way [14]:

$$\mathbf{R}_i = \Theta_i^{-1}\int\rho_i\mathbf{r}dV; \quad \mathbf{R}_{io} = \Theta_i^{-1}\int\bar{\rho}_i\mathbf{r}\, dV, \qquad (2)$$

where r is a running (Eulerian) spatial coordinate.

It follows that when such a system deviates from a homogeneous ("internally equilibrium") state, a certain "distribution moment" of the energy carrier arises

$$Z_i = \Theta_i(R_i - R_{io}) = \int_V (\rho_i - \bar{\rho}_i)\mathbf{r}dV \qquad (3)$$

with a ratio arm $R_i - R_{io}$, referred to as the "displacement vector" [14]. Since there are no processes in the equilibrium R_{io}, R_{io} can be taken as the reference point of $Z_i = \Theta_i R_i$. Thus, the differential dZ_i can be represented as the sum of three independent components:

$$d\mathbf{Z} = \mathbf{R}d\Theta_i + \Theta_i d\mathbf{r} + d\boldsymbol{\varphi}_i \times \mathbf{Z}_i \qquad (4)$$

where $\boldsymbol{\varphi}_i$ is the spatial (Eulerian) angle of the vector Z_i; $d\mathbf{r}_i$ is the shearing component of dR_i (at $\boldsymbol{\varphi}_i$ = const).

Three components of dZ_i correspond to three independent categories of non-equilibrium processes: 1) emergence of energy carrier Θ_i in the system or its introduction through the system boundary ($d\Theta_i \neq 0$); 2) its redistribution over the system volume ($d\mathbf{r}_i \neq 0$); 3) reorientation of the energy carrierin space ($d\boldsymbol{\varphi}_i \neq 0$). As a result, any i-th form U_i of its own (belonging only to the system) energy[1] U generally becomes a function of three independent parameters: $U_i = U_i(\Theta_i, \mathbf{r}_i, \boldsymbol{\varphi}_i)$. Thus, the total differential dU of the internal energy of the system as a sum of "partial" energies of all its forms $U = \Sigma_i U_i$ can be represented as an identity:

$$dU \equiv \Sigma_i\Psi_i d\Theta_i + \Sigma_i\mathbf{F}_i\cdot d\mathbf{r}_i + \Sigma_i\mathbf{M}_i\cdot d\boldsymbol{\varphi}_i, \quad (i = 1,2,..\, I), \qquad (5)$$

where $\Psi_i \equiv (\partial U_i/\partial\Theta_i)$ — generalized potentials ψ_i averaged over the volume of the system (absolute temperature T and pressure p, chemical potential of the *k*-th component of the system μ_k, its electric potential φ, gravitational potential ψ_g, etc.); $\mathbf{F}_i \equiv (\partial U_i/\partial\mathbf{r}_i)$ — generalized forces (external and internal, mechanical and non-mechanical, useful and dissipative); $\mathbf{M}_i \equiv (\partial U/\partial\boldsymbol{\varphi}_i)$ — moments of these forces.

Identity (5) represents the law of conservation and transformation of energy. According to this law, the energy of any natural system is divided into two parts — irreversible and reversible. The potentials of these two forms of energy differ insignificantly and are similar to the potentials of a calm and wavy ocean. Only the disturbed part, representing the wavy ripples of the ocean, is reversible. This part is characterized by the second and third sums in identity (5). Figuratively speaking, everything that is associated in nature with the energy of disturbed motion is a same fraction of the total energy of the global ocean of the Universe energy.

One of the most important advantages of the identity (5) is the elimination of the uncertainty of the energy concept and its definition as the most general function of the system properties characterizing its ability to perform any type of work. The identity (5) that connects the "conjugate" parameters Ψ_i and Θ_i, F_i and r_i, M_i and $\boldsymbol{\varphi}_i$, defines them regardless of what caused their change: external energy exchange or internal (including relaxation) processes. This prevents the well-known problem of the emergence of thermodynamic inequalities at transition to non-static processes, where the change of these parameters is caused not only by external energy exchange, but also by internal (relaxation) processes. This eliminates a major obstacle to applying the mathematical apparatus of thermodynamics to other fundamental disciplines. For the same reasons, the identity (5) is applicable not only to isolated systems as a whole (for which the volume V is unchanged and all processes are internal), but also to any of its material components, phases or areas, where parameters Θ_i, $\mathbf{r}_i$ and $\boldsymbol{\varphi}_i$ change also due to external energy exchange (heat transfer, mass transfer, diffusion, introduction of a charge into it, etc.).

In homogeneous systems ($\Psi_i = \psi_i$, $F_i = 0$, $M_i = 0$), the second and third sums of identity (5) vanishes, and it transforms into the combined equation of the 1st and 2nd principles of classical thermodynamics in the form of the generalized Gibbs relation [14], which

[1] It was called internal for a number of historical reasons.

describes the processes of equilibrium energy exchange of the system with the environment. After the introduction of time t as a physical parameter, the identity (5) formulated for isolated systems takes the form of the law of conservation of energy in its nonstationary form:

$$dU/dt \equiv \Sigma_i \Psi_i d\Theta_i/dt + \Sigma_i \mathbf{X}_i \cdot \mathbf{J}_i + \Sigma_i \mathbf{M}_i \cdot \boldsymbol{\omega}_i = 0, \qquad (6)$$

where $\mathbf{X_i} = \mathbf{F}_i/\Theta_i = \nabla\psi_i$ – strengths of field of force, expressed by gradients of generalized potential ψ_i (energodynamic forces) averaged over the system volume; $\mathbf{J}_i = (\partial \mathbf{Z}_i /\partial t)$ – generalized impulses of energy carrier Θ_i, referred to as "flows"; $\boldsymbol{\omega}_i = d\boldsymbol{\varphi}_i/dt$ — angular velocities of rotation (reorientation) of vector $\mathbf{Z}_i$.

In contrast to fundamental disciplines that study the processes of external energy exchange, this law provides an opportunity to consider internal processes in isolated (closed) systems, where the concepts of external energy, external forces, their work, momentum, etc. are meaningless. At the same time, energodynamics reveals the flow of three independent forms of internal work in such systems, performed respectively by "disordered" (scalar) forces, "ordered" (vector) forces and their moments. This radically changes the research methodology of all fundamental disciplines that do not consider internal processes, and makes it possible to move towards the study of internal processes determined by the above-mentioned system-forming connections.

IV. Systems Approach to Equilibrium and Non-Equilibrium Thermodynamics

Of all the fundamental disciplines, classical thermodynamics, being a deductive and phenomenological theory based on the principles of excluded perpetual motion machine of the 1st and 2nd kind, met the requirements of a systems approach to the greatest extent. It provided numerous consequences related to different fields of knowledge and earned the status of "queen of sciences" as a theory "the consequences of which will never be refuted by anyone" [21]. However, as it appeared, it had some known paralogisms when going beyond the strict limits of the validity of its initial concepts of equilibrium and reversibility. Most of them were related to the concept of Clausius entropy, which he introduced as a coordinate of heat transfer that was also dependent on internal heat sources [18].

The theory of irreversible processes (TIP), which emerged on the basis of the principle of increasing entropy using statistical-mechanical considerations and a number of additional hypotheses, did not avoid paralogisms either [25]. I. Prigozhin's local equilibrium hypothesis became the main one [23]. This hypothesis assumed the presence of equilibrium in the continuum elements (despite the relaxation processes occurring in them), the possibility of their description by the same set of variables as in the homogeneous state (despite the presence of potential gradients), and the validity of all equations of equilibrium thermodynamics for them (despite their inevitable transition to inequalities). Despite its inconsistency, this hypothesis made it possible to find the basic values used by TIP theory. However, this deprived TIP of the completeness and rigidity inherent in the classical thermodynamic method. All attempts to overcome these difficulties proved unsuccessful due to the lack of a thorough adjustment of the conceptual foundations and mathematical apparatus of classical thermodynamics.

This problem was solved by introducing additional extensive $\mathbf{Z}_i$ and intensive $\mathbf{X}_i$ parameters of the nonequilibrium state [14], and these parameters changed not only the structure, but also the methodology of explanation of the basics of equilibrium and nonequilibrium thermodynamics. An unconventional consequence of this approach is the proof that the true "dividing line" is not between heat Q and work $W^н$, which are included in the same sum of identity (5), but between different sums of this identity, i.e., technical $W^т$ and non-technical types of work $W^н$, the first ones being quantitative measures of the process of "energy conversion" (with a change in the form of energy), and the second ones — of energy transfer (without changing its form). These two types of work, referred to as "ordered" and "disordered", differ not only in the tensor rank of their coordinates $\mathbf{r}_i$ and Θ_i, but also in the presence or absence of the resulting overcome forces. The fact that "one work is different from the other" leads to the categorization of heat transfer as disordered work. This work is related to the transformation of the impulse of the system elements into a thermal impulse, which loses its vector nature due to thermal (chaotic) movement. Unlike entropy, thermoimpulse in thermally isolated systems can both increase and decrease, making it a true argument of internal thermal energy. Using it as an extensive measure of thermal motion instead of Clausius entropy S (as a coordinate of equilibrium heat transfer) makes it superfluous to interpret the latter as a measure of the thermodynamic probability of a state, which is incompatible with the concept of "entropy flux" used by TIP [26].

Energodynamics radically changed the methodology of nonequilibrium thermodynamics. TIP considers only the relaxation (purely dissipative) part of real processes. Instead, a new method of analyzing real processes was proposed on the basis of law (5) or (6) without excluding any (reversible or irreversible) part of them from consideration [14]. This became possible due to the identity (6), which allows finding the flows $\mathbf{J}_i$ regardless of the reason they are due to — relaxation ($\mathbf{X}_i \cdot d\mathbf{Z}_i < 0$) or performing useful internal work "against equilibrium" in the system ($\mathbf{X}_i \cdot d\mathbf{Z}_i > 0$).

Finding flows $\mathbf{J}_i$ and forces $\mathbf{X}_i$ directly from the identity (6), made it superfluous to formulate cumbersome equations of the mass, charge, momentum, energy and entropy balances for this purpose. This also excluded the arbitrariness characteristic of TIP in dividing the product $\mathbf{J}_i \cdot \mathbf{X}_i$ into factors with different meanings, values, and dimensions. This dramatically facilitated the application of the theory to various physicochemical processes and made it possible to propose a new method for their study. The essence of this method is to translate Onsager's laws from the matrix form-

$$J_i = \Sigma_j L_{ij} \mathbf{X}_j \qquad (7)$$

into a diagonal form with a smaller number of coefficients L_{ij} subject to experimental determination. This brought Onsager's laws closer to the equations of heat conduction, electrical conduction, diffusion, etc. Such a form did not need to apply the Onsager's symmetry conditions

$$L_{ij} = L_{ji}, \qquad (8)$$

and allowed to reduce the number of coefficients L_{ij} from n(n+1)/2 in TIP to nwhile preserving all information about the "superposition effects" of heterogeneous flows $\mathbf{J}_i$ and $\mathbf{J}_j$. Giving the transfer equations a diagonal form made the application of the Onsager reciprocity relations unnecessary, which significantly extended the scope of application of nonequilibrium thermodynamics owing to the violation of these relations in nonlinear processes. However, the possibility of applying nonequilibrium thermodynamics to non-static (occurring at a finite rate) energy conversion processes, which were previously considered in the so-called "non-dissipative" approximation, turned out to be even more important. This revealed the possibility of taking irreversibility into account in all fundamental disciplines [15].

The application of nonequilibrium thermodynamics to systems performing useful work has revealed the inapplicability of Onsager's "constitutive laws" (7) to such systems. The phenomenological laws of the process of energy conversion from the i-th form to the j-th one take the form in which their off-diagonal components (i ≠ j) have the opposite sign:

$$\mathbf{J}_i = L_{ii}\mathbf{X}_i - L_{ij}\mathbf{X}_j \qquad (9)$$

$$\mathbf{J}_j = L_{ji}\mathbf{X}_i - L_{jj}\mathbf{X}_j \qquad (10)$$

These laws reflect the interrelation and counterdirectivity of flows J_i and J_j in the processes of conversion of any forms of energy. For such processes, the reciprocity relations (9), (10) have an antisymmetric character L_{ij} = - L_{ji} and requires appropriate proof. Energodynamics leads to more general differential reciprocity relations [14]

$$(\partial \mathbf{X}_i/\partial \mathbf{J}_j) = (\partial \mathbf{X}_j/\partial \mathbf{J}_i \qquad (11)$$

Passing for linear processes into the Casimir anti-symmetry conditions $L_{ij} = - L_{ji}$ [27]. These relations required a TIP-independent and consistent thermodynamic justification of all positions of nonequilibrium thermodynamics. The consideration of counterdirectivity of flows at the input and output of the energy converter in relations (11) resulted in the development of original theory of similarity of processes of useful energy conversion. This theory proposed criteria of similarity of energy converters and universal dependences of coefficients of efficiency (COE) on the design perfection and operating mode of power plants. This has greatly improved the efficiency and practical benefits of thermodynamic analysis of thermal and non-thermal, cyclic and non-cyclic, forward and reverse machines in engineering calculations [14].

V. Systems Approach to Classical Mechanics

The presentation of mechanics usually begins with kinematics, which considers the motion of a point in space and time independently of the physical causes of that motion. At the same time, the concepts of motion trajectory, position of a point on it, its speed and acceleration are introduced by pure speculation. Only after that, the concepts of mass and momentum, which are the characteristics of a material point, are introduced, and the transition is made to the study of dynamics, which clarifies the reason for the emergence of this or that motion in various conditions and the laws to which it obeys.

At first glance, this structure of mechanics seems quite natural. However, as L. de Broglie fairly noted, this approach is based on the assumption that the results of abstract kinematic consideration can be further extended to the real motion of more complex mechanical subjects. Meanwhile, this is not always the case, and a systems approach to mechanics proves to be as useful as in other fundamental disciplines. From its perspective, the so-called "laws" of Newton's mechanics appear to be nothing more than postulates, which he called "definitions" for good reason. The limitations of these "definitions" are not always obvious and are sometimes revealed only when considering a more general range of problems [18]. This is, in particular, the Newtonian definition of force F = dP/dt as the time derivative t of the scalar "momentum" P = Mυ, which applies equally to both chaotic and directed motion. For the latter case, the concept of acceleration $\boldsymbol{a} \equiv d\boldsymbol{\upsilon}/dt$ became relevant to two fundamentally different processes: the change of the velocity modulus without changing its direction, and the change of the direction of the velocity vector without changing its absolute value. The concept of "centripetal acceleration" emerged when a point rotates uniformly around a circle, i.e., in the absence of motion toward the center. This led to the well-known paralogism of Rutherford's model of the atom on the basis of the erroneous statement about the inevitability of the electron falling on the nucleus due to its emission of energy during accelerated motion, despite the constancy of its kinetic energy.

From the perspective of the systems approach, the shortcomings of other initial concepts of mechanics are revealed as well [28]. For example, it is well-known that the motion of a single material point in the absence of external forces acting on it will be rectilinear and uniform (Newton's law of inertia). However, the uniform motion of bodies of finite dimensions "by inertia" can be both translational and rotational. This means that the law of inertia should have been generalized to rotational motion long ago. In that case there would be no reason to deny the existence of predominant reference frames. These examples and a number of others demonstrate the appropriateness of considering mechanics as an equal branch of physical theory like energodynamics as a single doctrine of forces. This approach generalizes all three of Newton's laws: the 1st law (of inertia) — for rotational motion, the 2nd law (of forces) — for forces of any nature ($\mathbf{F}_i \equiv \partial U/\partial \mathbf{r}_i$), the 3rd law (equality of forces of action and reaction) - for the case of simultaneous action of forces of the i-th and j-th nature ($\mathbf{F}_i$ = - $\Sigma_j \mathbf{F}_j$) [28]. Here it follows that the requirement of the directionality of the action and reaction forces, arising from Newton's 3rd law, applies only to the resulting forces $\mathbf{F}_i$.

However, it is even more important to find the law of gravity

$$F = G(Mm/r^2) \qquad (12)$$

for the case of continuum media where it is impossible to distinguish neither "field-forming" M, nor "test" m bodies. Such a law can be obtained directly from the equivalence principle of mass M_o and rest energy $U = M_o c^2$ by A. Einstein or from the previously obtained expressions of the ether energy. Expressing this principle through the matter density ρ and energy ρ_u, we have $\rho_u = \rho c^2$. Then, the intensity $\mathbf{X}_g = \rho \boldsymbol{g}$ of the gravitational field $\mathbf{F}_g$ is expressed through the matter density gradient $\nabla\rho$ by a simple relation [29]:

$$\mathbf{X}_g = c^2 \nabla\rho \quad \text{or} \quad \mathbf{g} = c^2 \nabla\rho/\rho. \qquad (13)$$

This law is not a generalization of Newton's law of universal gravitation (12), it is an independent law, which has paradigm (ideological) significance, since it implies the existence of not only the forces of "pushing" ($\nabla\rho > 0$), but also the forces of repulsion ($\nabla\rho < 0$), as well as gravitational equilibrium ($\nabla\rho = 0$). It is also of no less importance that gravitational interaction forces $\mathbf{X}_g$ are the most significant of all kinds of forces at equal density gradients of energy carriers $\nabla\rho$.

VI. Systems Approach to Quantum Mechanics

Nowadays it is difficult to imagine that the quantum-relativistic revolution could not have taken place if the apparatus of nonequilibrium thermodynamics had been developed in time, and instead of thermostatics the analysis of laws of radiation was based on thermokinetics. Back then, the idea of equilibrium with the cavity of the perfectly black body (PBB) would be replaced by the equality of flows of the absorbed and emitted energy that would immediately lead to understanding that the true radiation quantum is a wave modeled by PBB in the luminiferous medium, discrete both in time and in space. Then Planck's radiation law acquires a thermodynamic justification without involving Planck's postulate [30]. At the same time, the De Broglie relation expressing the wave-particle dualism is also proved, except that it does not refer to the wave properties of a particle, but to the particle-like properties of a soliton as a structurally stable wave. Then the position of E. Schrödinger becomes clear, as he believed until the end of his life that "what we take as particles are actually waves" [31]. According to energodynamics, radiation refers to ordered forms of energy exchange, therefore it must be described by the thermodynamic parameters of the process, not the state. Then the law of thermal radiation naturally follows from the concepts of classical physics without any preliminary postulates, but taking into account the fact that radiant energy is transferred by waves that are discrete in both time and space.

Furthermore, as follows from the principle of state determinism and the energy identity (5), each independent process inherent in the i-th form of energy U_i corresponds to a single state coordinate, i.e., a parameter that necessarily changes in the course of the process and remains unchanged in its absence. As it follows from the principle of counterdirectivity of processes, the deviation of such a value compared to the average value ($\rho_i - \bar{\rho}_i$)) has the opposite sign, as Franklin believed with regard to electric charge. Consequently, the search for an antipode for each energy carrier (like an electron and a positron, a particle and an antiparticle, positive and negative mass, etc.) leads to a redefinition of the system.

Finally, if N. Bohr had followed the systems approach when studying the emission process, he would have considered as a subject of study the entire set of atoms, located in external force fields and oscillating with them, rather than a single atom. Thus, it would become apparent that the emission or absorption of energy by an atom could only occur when the energy state of the electrons was determined by the action of external (non-central) forces F. Therefore, the reason of quantization of the emission energy is not the instantaneous "jump" of the electron from one stable orbit to another, but is the reaction of the electron to the influence of the external force field on it.

Thus, the contradiction between classical and quantum mechanics declared at the beginning of the twentieth century does not actually exist. It disappears in the light of the energy-dynamic concept: changes in energy in nature are caused by a discrete flow of energy carriers in the form of single waves. This means that there is no specific quantum physics with its own special laws, but there is a branch of unified physics that studies discrete (wave) processes. In this case, the true quantum of radiation is an ordinary wave, clearly discrete in both time and space.

Thanks to this approach, it is possible not only to justify the law of formation of spectral series as a consequence of the presence of harmonics of oscillations, but also to obtain the Schrödinger steady-state equation, which does not require comprehension in terms of probability theory [31].

VII. Systems Approach in Electrostatics and Electrodynamics

Electrodynamics as a fundamental discipline emerged from electrostatics, which studied the interaction of fixed charges. The Coulomb's law, established experimentally for two macroscopic charges of finite sizes but formulated for two point charges, is one of the initial principles of electrostatics. Hence, this formalization led to infinite values of force and energy when the distance between the charges was reduced to zero.

To eliminate this and other paralogisms, the use of the systems approach made it possible to formulate the mathematical apparatus of electrodynamics as a special case of the energodynamic identities (5) and (6) in their application to "current-carrying" systems [32]. The experimental Coulomb's law has the following form

$$F_e = (1/(4\pi\varepsilon_0)[(qQ_e)/r^2], \qquad (14)$$

where F_e — the modulus of the interaction force of charges q and Q_e; ε_0 — the electrical permittivity of vacuum. It corresponds to the potential of the electrostatic field $\varphi(\mathbf{r})$ as a measure of its potential energy at a point of the field $\mathbf{r}$ at a distance r from the "field-forming" charge Q_e:

$$\varphi(\mathbf{r}) = (1/4\pi\varepsilon_0)(Q_e/\mathbf{r}) \qquad (15)$$

The potential $\varphi(\mathbf{r})$ characterizes the attenuation of the electric field as it moves away from the center of a fixed "field-forming" charge Q_e, but it does not provide an idea of the change in the field potential as a function of the density $\varphi(_e)$ of the charge in it $_e$. At the same time, it is fundamentally important since the "primary cause" of the force $\mathbf{F}_e = -(\partial U_e/\partial \mathbf{r})_V$ is precisely the gradient of the electrostatic energy density $U_e = U_e(\rho_e)$, and the work W_e of moving the charge in the electrostatic field E is solely due to the heterogeneity of the field $\rho_e = \rho_e(\mathbf{r})$. For this purpose, we shall distinguish in space a sphere of unit volume V_0 with radius $r_0 = \text{const}$ and charge density $\rho_e = Q_e/V$, on a surface of which the potential $\varphi(r_0)$ has the same value. Then the expression (15) can be represented as:

$$\varphi(\rho_e) = V_0/(4\pi\varepsilon_0 r_0)\, \rho_e(\mathbf{r}) \qquad (16)$$

Here, the potential $\mathbf{r}$ is expressed as an implicit function of the field coordinate $\varphi(\rho_e)$, i.e., $\varphi(\rho_e) = \varphi[\rho_e(\mathbf{r})]$, and that preserves the meaning of the concept of the electrostatic field strength E as a negative gradient of this potential. Taking into account the constancy of the expression in brackets (16), we have the following

$$\mathbf{E} = -\nabla\varphi(\rho_e) = -(V_0/(4\pi\varepsilon_0 r_0))\nabla\rho_e$$

If we supplement the expression in brackets to the value of the potential of the sphere of unit volume $\varphi_0 = \rho\, V_0/(4\pi\varepsilon_0 r_0)$ or, we find

$$\mathbf{E} = -\varphi_0\, \nabla\rho_e/\rho_e \qquad (17)$$

This relation expresses the field form of Coulomb's law. It describes the electrostatic field as a function of the density gradient $\nabla\rho_e$ of the charge distributed in the field ρ_e. This relation (17) differs from the Poisson equation

$$\nabla^2\varphi = 4\pi\varepsilon_0\rho_e,$$

since it provides a direct relation between the electrostatic field and the local density of the "field-forming" charge ρ_e. It appears completely identical to Newton's law in its field form (13). It is fundamentally important that the generalized form of Newton's and Coulomb's laws (13) and (17) reveals the existence of forces of attraction and repulsion for energy carriers ρ_g and ρ_e of the same sign, demonstrating that this is not about them, but about their distribution in space. It is equally important that these laws reveal the existence of unstable equilibrium in gravitational and electric fields, prerequisite of this unstable equilibrium is the vanishing of the energy carrier density gradient:

$\nabla\rho_g = 0$ — gravitational equilibrium;

$\nabla\rho_e = 0$ — electrostatic equilibrium.

It should be noted that the existence of such equilibrium and the possibility of existence of fields with homogeneous distribution of masses and charges was not implied by the classical laws of Newton and Coulomb, where the forces of attraction or repulsion vanished only at infinity.

The transition to electrodynamics is connected with the interpretation of the electric current as a flow (impulse) of charge $J_e = Q_e \mathbf{v}_e$, conjugated with the electrodynamic force $\mathbf{X}_e = \nabla \mathbf{v}_e$. This force is a tensor in 2 dimensions and can be decomposed into a symmetric and antisymmetric part and a trace of the tensor which respectively form the vortex-free, vortex and scalar magnetic fields respectively. In this case, both torques and Nikolaev's forces arise, and there remains no room for statements that "the magnetic field does not perform work since the Lorentz forces are normally directed along the direction of motion" [33].

The understanding of the electromagnetic field (EMF) as a distribution in space of vectors E and H is fundamentally different from its interpretation by Maxwell as a medium carrying energy "after it has left one body and has not yet reached another one" [34]. It becomes clear why such "materialization" of EMF was not accepted by any of the researchers of that time and, in particular, by W. Thomson, who referred to this field theory as "mathematical nihilism". Indeed, the existence of EMF, "detached" from its source, led to a conflict with the law of conservation of energy, according to which the energy of EMF is equal to the sum $\varepsilon_o E^2/2 + \mu_o H^2/2$, where E and H are the intensities of its electric and magnetic components; ε_o and μ_o are the "electric and magnetic permittivity" of vacuum. In an electromagnetic field, the intensities E and Hchange in-phase, which was proved by Faraday. Therefore, the EMF energy cannot remain constant when isolated from the sources. The transfer of electromagnetic oscillations in the environment discovered by Hertz did not provide a definite answer about the nature of the environmental oscillations themselves. They are not necessarily of electromagnetic nature. Hertz's experiments, revealing the transfer of electromagnetic oscillations in the environment from one body to another, didn't prove that the same kind of oscillations are inherent in the "luminiferous" medium itself. Such transfer can be realizedas a result of conversion of electromagnetic energy of the source into the energy of density oscillations of the "luminiferous" medium with their inverse transformation into electromagnetic oscillations in the radiation detector. This was claimed by N. Tesla, who discovered a special kind of "radiant" ("cold") electricity in the ether [35].

VIII. Systems Approach in Biochemistry and Biophysics

In biological systems, supplementary non-additive properties that require a systems approach are the following: the existence of "active transport" of matters (their transfer to the area of increased concentration), the phenomenon of "conjugation" of chemical reactions (when some of them go in the direction opposite to the chemical equilibrium), their ability to "self-organization" (structure formation), and so on. All phenomena of this kind are anti-dissipative in their nature, and according to I. Prigozhin's fair remark, this fact "flagrantly contradicts to thermodynamics". (I. Prigozhin). Thereby, the thermodynamic analysis of biological systems encounters significant fundamental challenges [36].

One of the ways to overcome these challenges is to consider any biological cell as a complex (polyvariant) system. This approach requires considering its structure (spatial heterogeneity) to the same extent as in macrosystems. Therefore, all the observations made earlier with respect to extensive Z_i and intensive $\mathbf{X}_i$ non-equilibrium parameters of the systems under study are valid for this purpose.

The next step is the refusal to justify the laws of biophysics on the basis of the theory of irreversible processes, since the latter does not consider the reversible component of real processes [17]. The performance of useful work by a biological system is one of the main signs of its vitality. As it is known, the maintenance of the non-equilibrium state of biosystems is accomplished by supplying it with free (ordered) energy from the outside. Therefore, the exclusion of the processes of performing useful work as described by the second sum of identity (1) from consideration is the same as "splashing out the water and the child as well".

Under the systems approach, vector flows J_i and forces $\mathbf{X}_i$ are determined not on the basis of the expression for entropy "production" dS/dt (as it was proposed by I. Prigozhin), but on the more general basis of the law of conservation of energy in the form (6). In this case, the product $J_i \mathbf{X}_i$, which characterizes the power of the process, reflects not only the relaxation processes ($J_i \cdot \mathbf{X}_i < 0$), but also the processes of removing the system from equilibrium by performing the internal work "against equilibrium" in it ($J_i \mathbf{X}_i > 0$). In biological systems, the postulated Onsager-Prigozhin linear kinetic laws (7), (8) are replaced by true «phenomenological» laws (9), (10) and (11), which have a reversible component (with the opposite sign of the off-diagonal components ($i \neq j$). They proved to be valid for processes of "active transport" of matters in biological systems, as well as for "ascending diffusion" in alloys, for electrolysis, dissociation, "self-organization", and so on, i.e., for all processes where the work "against equilibrium" is performed.

The systems approach also makes it possible to eliminate the contradiction of TIP with the Curie principle, according to which the flows J_j can depend only on thermodynamic forces X_i of the same (or even) tensor. In particular, scalar chemical reactions referred to in TIP as $\Sigma_r A_r d\xi_r$ (where A_r is the standard chemical affinity of the *r*-th chemical reaction, ξ_r is the degree of

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its completeness) cannot interact with metabolic processes of vector nature. Meanwhile, these are precisely the processes that play a key role in supporting the vital activity of biosystems. Prigozhin's hypothesis of "steady-state conjugation", which he put forward to overcome this difficulty, appeared to be unsatisfactory, since the mentioned interrelation is also preserved in non-stationary behaviors that are typical of biological systems.

Once again, the systems approach becomes useful here. According to this approach, chemical reactions in cell membranes, flow reactors, fuel cells, Van't-Goff boxes, and so on also acquire a vector character, and in this case, the function of the thermodynamic force of the r-th chemical reaction is fulfilled by the value $\boldsymbol{X}_r = \nabla A_r \xi_r$, conjugated to the flow of reagents J_r involved in it, which corresponds to the Curie principle [14].

Thus, the evidence reveals the limited applicability of the theory of irreversible processes to biological systems and the "inductive" construction of chemical physics and biophysics by extrapolating TIP to biological systems. In this regard, the crucial role is played by the replacement of entropic criteria of evolution by non-entropic ones, which are expressed directly by the moments of distribution of energy carriers Z_i or by forces $\mathbf{X}_i$, capable of increasing and decreasing in real processes. Such criteria can reflect not only the proximity of the system to equilibrium (its involution), but also its removal from it (evolution) [17]:

$d\mathbf{X}_i > 0$ (evolution); $d\mathbf{X}_i < 0$ (involution).

The introduction of more "physical" and intuitive criteria of evolution and involution provides an opportunity to reflect the behavior not only of the system as a whole ($\Sigma_j X_j dZ_j \neq 0$), but also of each degree of its freedom, i.e., it is more informative than entropy. It becomes obvious that the processes of "self-organization" in isolated systems ($dU = 0$) are the ordering of some (*i*-x) degrees of freedom due to the "disordering" of others (j-x) [17].

The systems approach enables to find a law of biological evolution that does not contradict classical thermodynamics. To achieve this, it is sufficient to compare the time it takes for a biosystem to reach a state of internal equilibrium in the presence and absence of evolutionary processes in it $X_j dZ_j > 0$. Then it becomes apparent that the evolutionary processes occurring in biological systems increase the duration of their reproductive periods. Therein lies the reason for the general orientation of the progressive evolution of biological systems, which is understood as a transition from simple to complex. Such a delay in achieving equilibrium in biosystems is close to the Darwinian idea of survival, and therefore it can be considered as an alternative to the rather straightforward idea of the "struggle for existence".

IX. Systems Approach to the Analysis of Physical Vacuum

Until recently, physics, thermodynamics, physical chemistry and other sciences have studied energy transfer in the real (structured) part of matter, which is no more than 5% of the Universe. However, the main energy transfer occurs in the remaining hidden mass of unstructured matter, which has only an oscillatory form of motion with a continual spectrum, which contributes to its invisibility (hence the term "dark" matter) [37]. Therefore, it is only natural to consider the environment in the form of unstructured matter (pre-matter) as a continual set of oscillators with a background frequency spectrum. Pre-matter oscillators are traveling waves that carry energy. Radiators, i.e., oscillators of matter represented as structured forms of baryonic matter (electrons, protons, neutrons, atoms, molecules, nanoparticles, plant cells and living organisms) transform the energy of pre-matter into its other forms as closed (standing) waves, which number is countable [5, 8]. The vibrations of the matter oscillators are transferred to the environment, modulating traveling waves in it with a spectrum different from the continual (background) one, making the structured matter visible ("light"). For an observer, structured matter is perceived by distinguishable radiations: light, thermal, electromagnetic, X-ray, chemiluminescence, photoluminescence, electroluminescence, radiant, torsion, microlepton, chronal, biofields, and others.

The analytical model of the origin of matter oscillators in the form of electron, proton, and neutron from pre-matter was first developed by N. A. Magnitsky (2010) [38-40]. The mechanism of interaction of matter and pre-matter in the form of convolution of a traveling wave into a closed wave of doubled period is proposed, resulting in two elementary particles with rest mass and opposite spins. It is shown that the electron is the first simplest period-doubling bifurcation from an infinite cascade of bifurcations in accordance with the universal Feigenbaum-Sharkovsky-Magnitsky (FSM) theory [40]. According to this theory, the discovered elementary particles are far from exhausting the infinite set of elementary particles that can appear as a result of bifurcations in the nonlinear system of equations of the pre-matter motion dynamics. Hence, two important consequences follow: 1) structured matter emerges from unstructured matter continuously, as does the reverse spontaneous decay of baryonic matter as a result of radioactive emission; 2) attempts to experimentally detect both the simplest (most elementary) and the most complex of elementary particles are unpromising. Instead of the point elementary particle concepts considered in theoretical physics, the wave internal structure of elementary particles as well as atoms and molecules of matter is justified. As a result, for the first time, an analytical description was given, reliably confirmed by experiments, of the structure of atoms of all chemical elements included in the table of D.I. Mendeleev from the positions of classical mechanics, whereas the table itself was returned to its original state [39], which had previously been distorted by numerous adjustments to the unsubstantiated postulates of the traditional quantum theory.

According to energodynamics, any wave (acoustic, hydraulic, electromagnetic, ether, etc.) is similar to a dipole, which determines the force nature of its interaction with the matter. Furthermore, the force manifests itself as a gradient of the amplitude-frequency potential [41]. Due to this, any interactions performed by oscillating intermediate medium, no matter how it is referred to (ether or field) also acquire a force nature, which is determined not by any special nature of acting forces, but by resonance amplification of energy exchange at the frequencies of natural oscillations of various structural elements of interacting agents. In energodynamics, this type of interaction is called resonant selective.

This interaction nature is confirmed by numerous phenomena of resonant absorption or emission observed in all fields of natural science. The resonant selective force interaction in the matter can be performed by the field of any oscillating scalar magnitude, i.e., it is not necessarily electromagnetic. In particular, the following can be considered: resonant absorption of energy of elastic or electromagnetic waves; "indifference" to atoms of a different "type", expressed in the concept of partial pressure; interaction of different chemical reagents in multiples defined for each of them; catalysis in chemical reactions; selective conductivity of membranes against different substances and solutions; selective absorption of certain substances by the surface of bodies; diffusion, osmosis, filtration of substances through semiconductor membranes; synchronization of radiation frequencies in lasers; selective interaction of proteins with RNA and selective effects of pharmaceuticals on the organism; preferential reproduction of certain ones and destruction of others in the processes of evolution, and so on and so forth.[42].

X. Systems Approach to Astrophysics and Cosmology

At present, a true cosmological revolution is taking place, originated by the improvement of technical instruments of observational astronomy and characterized by an avalanche-like growth of new knowledge about the Universe. One of the fundamental results was the confirmation of the presence of two forms of matter in the Universe — observable and unobservable, referred to as ether, and after its expulsion from physics — hidden mass, physical vacuum, dark matter, etc. As it was mentioned above, the "visible" mass is not more than 5% of the matter amount in the Universe, and most of it is "hidden" (dark) and is not involved in electromagnetic interactions. The latter means that among the four types of interaction known to science only gravitational interaction is the only one left for it, so it shall be considered as the main form of energy of the Universe. The transformation of gravitational energy into other forms, discovered as early as in Galileo's experiments, is the basis of all evolutionary processes occurring in it. However, in order to prove it, it is essential to find a "primary" material carrier of gravity, which has an all-pervasive ability and can transform into any other forms of matter of the Universe. At this point, the knowledge that has reached us from the depths of millennia proves to be useful. The knowledge is about the existence of invisible and intangible "subtle" matter, which originally filled all the available space. And from this "subtle" matter the "rough" matter, which has boundaries and is called substance, was formed by compaction. In ancient India this medium was called "Akasha", in Europe of the Middle Ages — ether, and in post-classical physics — "hidden mass", "physical ("cosmic") vacuum", "dark matter", "dark energy", etc. The modern paradigm classifies this form of matter as field matter, which differs from matter in its continuity (lack of structure). All known forms of matter in the universe arose from it. The main feature of the "field medium" is the absence of boundaries, i.e., the ability to occupy the entire space without any voids. This property means that it is an indispensable component of any material system and it is included in identities (5) and (6) along with other material components.

According to modern data, the density of the field medium ρ_o is ~10^{-27} g cm^{-3}, which is by dozen orders of magnitude less than the density of white dwarf stars. This is evidence of the heterogeneity of the matter of the Universe and the validity of the principle of counter directivity, with all the following consequences. One of them implies the possibility to consider the identity (6) as an "equation of the Universe", especially since it describes the entire set of processes occurring in it, besides the relationship between the space-time curvature and the energy-momentum tensor. The main advantage of this "equation of the Universe" in comparison with the well-known Einstein-Hilbert-Friedman model is that it does not require any hypotheses and postulates, it does not contain any concepts unfamiliar to classical physics, it does not contradict the law of conservation of energy and does not impose upon the Universe the simultaneous occurrence of the same processes in all its areas ("multiverses"). On the contrary, it indicates the inevitability of the counterdirectivity of the processes of evolution ($d\mathbf{Z}_i>0$) and involution ($d\mathbf{Z}_i<0$) in different areas of the Universe (galaxies and metagalaxies) and the possibility of simultaneous occurrence of such processes in the same areas of the Universe [17].

Another consequence of the systems energodynamic approach to the Universe is the validity of the bipolar law of gravity (8) with all its predictive capabilities [17]. According to this law, gravity is not an "innate property" of hidden matter, but it is due to the uneven distribution of its density in space. Furthermore, according to (8), the action of the gravitational forces F_g at a given point of space is directed along the density gradient of the latent mass $\nabla\rho_o$ in it. This means that in the area $\rho_0 > \bar{\rho}_0$, any material point is subject to "pushing" forces acting towards the area of increased density, which intensify the field heterogeneity spontaneously arisen in it. On the contrary, where $\rho_0 > \bar{\rho}_0$, there are "repulsion" forces, aiming to "move apart" such areas. Similar to the behavior of grease spots on the water surface, this results in the emergence of "voids" and explains the "scattering" of galaxies from each other as they compact without increasing the already infinite space of the Universe. This made it possible to construct a theory of gravity that predicts the formation of local condensations of hidden matter as spherical solitons forming the nuclei of future atoms, the formation of spherical shells of atoms of various substances around them, their combination into molecules, gases, liquids, solids, and so forth up to galaxies and their clusters [43]. This evolutionary branch of the Universe matter circulation comes to an end when the compression forces of the star, weakening with increasing density ρ, can no longer restrain the growth of internal pressure under the influence of thermonuclear reactions. This is when the "supernova explosion" occurs, which means the beginning of its involution and decay up to the initial state.

Another most important consequence of law (13) is the acknowledgment of gravity as the strongest of all interactions. It follows from the fact that the proportionality coefficient c^2 in (13) is at its maximum near the hidden mass, decreasing in optically dense matter by its refractive index. For this reason, Coulomb forces are weaker than gravitational ones, especially since the density of charges in a matter ρ_e is less than its density ρ. This turns the hidden mass into the "fuel of the Universe", since the energy $c^2 \Delta M_o$ released during "condensation" (realification) is 931.5 MeV/a.m.u., which is orders of magnitude less than the heat release of thermonuclear reactions. The evidence of this is the higher temperature of the photosphere.

Other consequences of the law of gravity (8) are also experimentally verified: the character of their rotational curves due to the density gradient of the matter of spiral galaxies, the existence of autonomous gravity zones near the Earth and the Moon (gravity funnels with different sign $\nabla\rho_0$), the matter flowing over from one galaxy to another (with larger $\nabla\rho$) in the absence of convergence of their centers, the concentric arrangement of star clusters at a certain distance from the central ones, indicating their gravitational equilibrium, etc. [17].

The consequences of the systems energodynamic approach question the scenario of the origin and death of the Universe, derived from the analysis of the well-known Einstein-Hilbert-Friedman equation of the Universe. Indeed, it is sufficient to present this equation in the form of an integral taken over space (taking into account the spatial heterogeneity of the Universe), as it becomes obvious that all the consequences of its analysis should be attributed only to some of its areas. The nonstationary behavior of the Universe as a whole, the counterdirectivity and non-synchronism of processes due to delayed perturbations become obvious as well as the possibility of functioning of the Universe unlimited by time and space, bypassing the equilibrium state [44].

XI. Conclusion

A system-energodynamic approach to the construction of fundamental disciplines on a unified basis is formulated. This allows us to get rid of many paralogisms caused by the inductive nature of the construction of physics, based on a postulative (model) approach to describing the mechanisms of natural phenomena. The combination of inductive and deductive research methods significantly expands the horizons of natural science, in particular, it enriches the methodological base of engineering disciplines, opening up new ways and methods for solving practical problems.

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Optimizing Smart Factories: A Data-Driven Approach

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Abstract- Since the first industrial revolution, the leading role of emerging technologies has been highlighted in modernizing the industry and developing the workforce. This study explores the impact of Industry 4.0 digital technologies on manufacturing competitiveness, focusing on Finnish SMEs within the EU with a sample (n = 123). It utilizes extensive 2022 European Manufacturing Survey (EMS22) data. Advanced statistical techniques reveal complex connections between automation, competitive edge on services, and innovation models, among other factors. Robust statistical methods, including component and reliability analyses, reinforced the findings. The conclusion offers critical insights and identifies areas for further research in combining innovative manufacturing practices with technology education.

Keywords: industry 4.0; competitiveness and employment, supply chain contracts, human resources, training and competence development, business innovation model, digital services, digital elements, product related services, cybersecurity practices, key enabling technologies, organization concepts, relocation activities, factor analysis.

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Janne Heilala α, Antti Salminen σ, Wallace Moreira Bessa ρ & Jussi Kantola ω

Abstract- Since the first industrial revolution, the leading role of emerging technologies has been highlighted in modernizing the industry and developing the workforce. This study explores the impact of Industry 4.0 digital technologies on manufacturing competitiveness, focusing on Finnish SMEs within the EU with a sample (n = 123). It utilizes extensive 2022 European Manufacturing Survey (EMS22) data. Advanced statistical techniques reveal complex connections between automation, competitive edge on services, and innovation models, among other factors. Robust statistical methods, including component and reliability analyses, reinforced the findings. The conclusion offers critical insights and identifies areas for further research in combining innovative manufacturing practices with technology education.

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I. Introduction

This study's central motive is to quantitatively assess the impact of Industry 4.0 digital technologies on manufacturing competitiveness, specifically within the context of European Union Finnish small and medium-sized enterprises (SMEs). The alignment within the EU's strategic priorities is to modernize industry. Preparing the workforce in education and training means examining how technologies like automation and robotics applications can be integrated and leveraged. By utilizing the European Manufacturing Survey 2022 (EMS22) dataset tailored to the Finnish manufacturing sectors, the study aims to gain granular insights into SMEs' adoption and use of the manufacturer's key enabling technologies. The quantitative analysis of survey data provides data-driven perspectives to inform decision-making for Industry 4.0 integration.

The manufacturing industry has undergone significant transitions over centuries, from the advent of steam power and assembly lines in the 1750s (Industry 1.0) to the rise of global supply chains and localized production goals (Industry 2.0), and then progressive automation and digitalization since the 1960s (Industry 3.0). These advances have been driven by innovation and connectivity needs (Heilala, 2022). Today's environment demands extreme customization and efficiency. This motivates embracing technologies like automation and robotics, moving towards Industry 4.0. Such technologies are critical for European Union (EU) small and medium-sized enterprises (SMEs) to bolster competitiveness. The EU aims to strategically modernize industry and develop workforces for the future (Heilala, 2022).

This research utilizes the EMS, which has tracked Europe's industrial progression for two decades, offering a rich dataset. The EMS is an extensive survey conducted across European countries that collects key information on manufacturing strategies, technologies, and practices. It provides valuable insights into the state of the industry and how it is evolving amidst digital transformation and Industry 4.0 trends. The EMS adopts a broad perspective on manufacturing evolution, complementing the innovation-focused Community Innovation Survey (CIS) grounded in the OSLO framework (Consortium for the European Manufacturing Survey 2020; Dachs & Zanker, 2015; European Commission et al., 2015). The refined EMS22 survey shows, by each question, The quantified variables of a representative sample of 123 small firms. As per leveraging EMS data, the impact of digital transformation on competitiveness is analyzed. The analysis applies exploratory factor analysis, structural equation modeling, and logistic regression to evaluate variable relationships on testing proposed hypotheses to form the logistic regression model. Key results reveal complex interdependencies between innovation models, technologies, services, and performance. The discussion interprets these insights, outlining empirical connections found and limitations encountered. The statistically driven findings contribute to the discourse on digital competitive advantage, providing a modeling foundation for ongoing research into optimizing smart manufacturing implementation.

II. Literature Review - Decade-Long Perspective

a) Analytical Review of Manufacturing Research Trends

Prior EMS-based studies have utilized diverse statistical methods to analyze the survey data. The scoping review includes component analysis, reliability analysis through alpha, rho, and omega, and exploratory and confirmatory analyses. Structural path analysis shows multivariate analysis for discriminant and convergent validity assessments to implement in response to information characterization. Prior studies

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have shown depth in trade (European Commission, 2016; Kinkel et al., 2015). The lookup followed the format 'TITLE-ABS-KEY ("manufacturing" AND "statistic method")' to identify publications similar in the metadata. Results were filtered by year (2013-2023) for trends in Figure 1. The usage of each component's method used in manufacturing literature (2013-2023) needed to be more extensive. The internal structures' lower reliability frequency and the current research gap were identified.

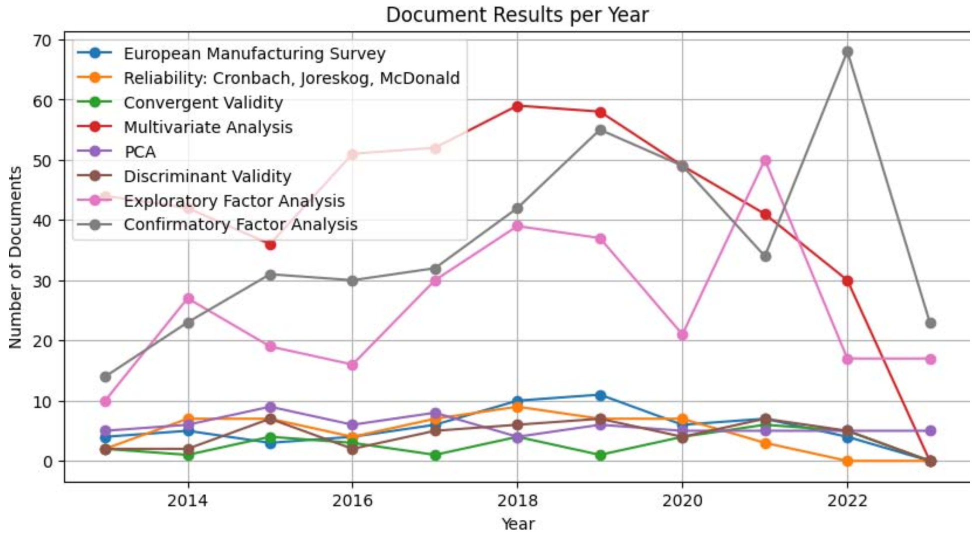

Figure 1: Trends for the Statistical Methods used in Manufacturing Method Studies (2013-2023) (Scopus 2023)

While the analysis criteria development established the management domain, the gap in examined publication trends is shown. The scope highlights increased utilization of exploratory and confirmatory factor analysis while other areas decline. The current study is aligned with the use of pre-defined variables from key themes from the EMS 2022 survey to fill the gap. The analysis incorporates a meta-level surfacing the variables from the EMS2022 survey across categories, including competitiveness and employment metrics, supply chain contracts, human resources distribution, training initiatives, business innovation models, implementation of digital services, adoption of digital elements, provision of product-related services, cybersecurity practices, utilization of key enabling technologies, organization concepts, and prevalence of relocation activities abroad (Table 1).

Table 1: The study's classification development baseline adapts to EMS22 statements, testing if the practice is used for the context frameworks (EMS, 2022). The questions on the development of competitiveness and employment (DCES) are measuring manufacturing digitalization, acronymized as European manufacturing survey's (EMS's) key enabling technologies (KETs); organizational concepts (OCs) for relocation activities (RAs); digital services (DSs); cybersecurity practices (CPs) from the supply chain contract (SCCs) and resources (HR) perspectives. This shows that each of the factors explained is emerging in the experimental factor analysis addressed sample.

Category	Variables
Competitiveness and Employment	Annual turnover, number of employees, manufacturing capacity utilization, return on sales, investments in equipment and machinery, annual payroll as percentage of turnover, year of establishment.
Supply Chain Contracts	Manufacturers, suppliers, contract manufacturers.
Human Resources Distribution	University/college graduates, technically skilled workforce, trained workforce, semi-skilled and unskilled workers, trainees each segment indicating that practical skills and in-house training are highly valued in the workforce.
Training Initiatives	Task-specific training, cross-functional training, support in digital implementation, data security and compliance training, creativity, and innovation training.
Business Innovation Models	Distribution, access, maintenance service-based, high-performance computing, on-demand, sharing, performance, and turnkey innovative economies.
Digital Services Implementation	Customer contact platforms, digital standard solutions, automated customer interactions, remote access control elements, cloud and IoT solutions, big data analysis.
Digital Elements Adoption	Identification tags, sensor technology, interactive interfaces, real-time network connection, digital transformation technologies.

Product-Related Services Provision	Installation and start-up, maintenance and repair, training, remote support, design and project planning, prototype development, revamping and modernization, take-back services, software development.
Cybersecurity Practices	Data security awareness, software solutions, hardware solutions, organizational measures.
Key Enabling Technologies Utilization	Production control, automation and robotics, efficiency technologies, simulation, data analysis, additive manufacturing.
Organization Concepts	Organization of production, management, and control, such as lean management, quality circles, and continuous improvement processes highlight the significance of organizational culture and structure in driving performance and adaptability.

Sustainable manufacturing is the creative process of synergizing the supply chain components. The enhanced competitiveness is a sign of good manufacturing for maintaining operations. It is reflected in key EMS variables related to innovation. Innovativeness requires automating human capital development for efficiency (Chia-Yen & Andrew, 2015; Mehta et al., 2010). Aligning with Europe's 2020 strategy goals, the Scopus review has limitations to the latest EMS data. Studying and assessing relationships between digital transformation, competitiveness, and employment within Finnish manufacturing is a top priority (European Commission, 2014).

b) Research Hypothesizes

The review preliminaries show eight hypotheses developed to align with the analysis methods subsequently presented in the literature. The hypotheses show predictive relationships between EMS22 survey variables and manufacturing competitiveness and employment status for managing new natural law for technologist implications. The analysis tests hypotheses on the influence of EMS variables related to competitiveness and employment metrics (integer/binary),
which are:

H1. Business innovation model variables
H2. Digital service implementation variables,
H3. Digital element adoption variables,
H4. Product-related service provision variables,
H5. Cybersecurity practice variables,
H6. Key enabling technology utilization variables,
H7. Organization concept variables, and
H8. Relocation activity variables, that

Have an explicit connection to Finnish manufacturers' competitiveness and employment. Anonymization was applied to model the small enterprises on the modeling path for a general overview. Competitiveness and employment status show the sample balanced challengingly with various sectors. The general model of the multivariate analyses between variables is usable for remote measurement of the firm floor-level relationships when fitted with normalized scores. The hypotheses assume the specific hypotheses of connections explore the exploratory model and the bottom-level quotes to converge for discussion. Thus, the literature review of analysis methods considers exploratory factor analysis to assess the underlying factor structure. The measurement models against the survey data follow the factor structure evaluation. Structural path visioning shows the Tested hypothesized relationships advantaged to classify the sample. Reliability analysis for discriminant and convergent validity assessments validates the construct's internal validity. This EMS data derives the measure to manage small chains by a quantitative approach aligned with analyzed studies.

III. Multi-analytic Research Methodology

Over time, the manufacturing studies trends from Scopus show applications to analyze manufacturing survey data. Findings of analyses type sorted (e.g., Kinkel et al., 2015; European Commission, 2016). A requirement to utilize factor analysis with structural path analysis is to establish an augmentation to explore relationships between variables from the latest EMS data. As such, explorative factor analysis is applied to assess the underlying factor structure with linear regression. The confirmatory on-path evaluation shows the measurement models on the survey data to the lagged binary correspondence. This was adapted to logistic regression with industry responses, reporting reliability to the causal treatment domain, see, e.g. (Wang et al., 2020; Gomila, 2021). For the detailed analysis, with the depth of linear analyses, utilizing logistic regression helped deal with binary data for drawing dedicated results. The grounding is considering traditional model fit indices for likelihoods. The accuracy on the analysis-dependent level is usually based on statistical principles (Hilbe, 2009; Casella & Berger, 2002; Hosmer Jr. et al., 2013). The approach offers coefficient interpretation in terms of associations between the variables studied. The regression path shows the hypothesized relationships influencing manufacturing competitiveness and employment component space. Reliability analysis shows internal consistency (Taber, 2016). discriminant and convergent validity validated in further models of measurement (Anderson & Gerbing, 1988).

IV. Data-Analysis

A sample (n=123) encompassed diverse industrial classifications to capture a breadth of product types and business models as classified (Heilala & Krolas, 2023). The data was acquired through Webropol's natural language collection tool and underwent cleaning to remove irrelevant responses (Webropol, 2022). The refined dataset was coded for frequency, reliability, and component analyses. Reliability analysis of the EMS2022 constructs was used to reveal internal consistency values. For reliable data, a partial technique across Industry 4.0 sectors established interpretable results (Bozgulova & Adambekova, 2023; Juariyah et al., 2020). Utilizing over 50 sub-items from the EMS22 survey represents a framework. Analysis of growth strategies in manufacturing, focusing on technologies, practices, and their impact on competition and employment industry-wide.

This spectrum of the manufacturing sector shows' manufacturing of metal products and 'Manufacturing of machinery and equipment,' and the software sector is most prominent. Industry sectors held a more miniature representation on each side for diversity and possibilities (Heilala & Krolas, 2023). The manufacturing industry studies have not been interested in industry-wide participatory studies (EMS, 2022; European Commission et al., 2015). Participation is included in the varied scope of industrial manufacturing, from factory assemblies to comprehensive lifecycle process assessments. Studies have usually served customers with platform requirements, such as within construction industry (He et al., 2018).

a) Convergent and Congeneric Reliability Levels

Component analysis was used for dimensionality reduction to measure the reliability of constructs. The Cronbach Alpha, Jöreskog's Rhô, and McDonald's omega were followed as in Table 2 (Taber, 2016). Alongside the analysis of several items (survey questions or statements used), the measures of internal consistency indicate a set of items' interrelation. A higher value suggests that the items measure the same concept.

Table 2: Construct Reliability Levels Show Higher Reliability for Constructs, Abbreviations Explained Below, Indicating Strong Internal Consistency with High Measurement Accuracy

	Items	Cronbach's Alpha	Joreskog Rhô	McDonald's Omega	val.
DCES	4	0.900	0.803	0.867	62
BIMs	6(7)	0.765	0.530	0.505	59
DSs	6	<.50	<.50	<.50	88
PRS	17	.825	0.824	.839	105
DEs	5	.799	0.865	.812	106
CPs	4	<.50	<.50	<.50	105
KETs	18	0.951	0.595	0.755	123
OCs	11	0.803	0.889	0.659	120
RAs	3(4)	0.900	0.885	0.583	80

Several constructs in Table 2 exhibit poor reliability per the coefficient values below 0.5. In the stats table, DCES (developing competitiveness and employment stats) measures various aspects such as AT (annual turnover) and NE (numbers of employees) to the other factory specifics, showing high reliability in all coefficients and suggesting it is a well-measured construct. On the contrary, BIM (business innovation models) has moderate reliability, indicating the varying degree of integration that could be the first varying signal of innovation potential within firms. Surprisingly, DSs (digital services) exhibit poor reliability, raising concerns over the effectiveness of these measures in capturing companies' digital transition. PRS (product-related services) demonstrated robust reliability across all coefficients for services provided, reflecting customer relationship on maintenance services. The high-reliability scores were affirmed for DEs (digital elements). Poor reliability for CPs (cybersecurity practices) has indicated potential issues in consistently measuring how digital infrastructure is safeguarded. Despite moderate reliability, KETs (key enabling technologies) benefit the omega display because it has a broad scope of moderate reliability measures regarding a few item combinations that align with each other. Similarly, but contrary to omega, OCs (organization concepts) present reliable measures contributing to firm efficiency and agility. Uniformity to globalization, RAs (relocation activities) exhibit varied reliability across coefficients. The first signal to the empty tabulations shows Heilala and Krolas (2023), who note that the carbon footprint in offshore locations needs to be more consistently optimized by reassessing certified systems.

b) Factor Analysis

Despite a few constructs having insufficient reliability for further analyses, another angle to considering partial exploratory factor analysis (PEFA) was taken. PEFA was an intriguing option to form over an established, validated framework of the survey metrics. The technique has been used across manufacturing and other Industry 4.0 sectors, reliably increasing safety to select the analysis method (Bozgulova & Adambekova, 2023; Juariyah et al., 2020). Factor analysis provides insights into the multivariate relationships of survey instruments (Creswell, 2015; Edmonds & Kennedy, 2019). PEFA shows the interconnections between factors influencing the instruments (Matsunaga, 2010; Revelle, 2013). Rotation methods of VariMax and ProMax optimize factor separability (Matsunaga, 2010). The PEFA is shown in the Table 3 model DCES (developing competitiveness and employment situ) measures of annual turnover for 2019-2021 (AT19/21; m23a1, m23a2), employee numbers for 2019-2021 (NE19/21; m23b1, m23b2), capacity utilization for 2019-2021 (MCU19/21; m23h), return on sales for 2019-2021 (ROS19-21; m23i1-5), investments (m23f), payroll percentage (m23g), and establishment year (m23k) reflect financials, labor dynamics, asset efficiency. High turnover and employment correlate with competitiveness. Supply chain contract (SCC) types categorize operators as manufacturers (MFR; m03a1-a3), suppliers (SPLR; m03a4-a5), or contract manufacturers (CM; m03a6), capturing production system roles. Manufacturers' negative SCC correlation potentially signals inflexibilities, unlike positively correlated suppliers and contract manufacturers benefitting from dynamic agreements. Human resources (HR) distribution classifies graduates (m16a1), technical staff (sm16a2), trained workers (m16a3), semi/unskilled personnel (m16a4), and trainees (m16a5), measuring skills and qualifications. Graduates' negative HR correlation potentially reflects oversaturation, contrasting positives for vocational abilities. Business innovation models (BIM) like leasing (BIM1; m18a1), service contracts (BIM2; m18b1), output-based services (BIM3; m18c1), sharing models (BIM4; m18d1), availability guarantees (BIM5; M18e1), and turnkeys (BIM6; m18f1) integrate variably, signaling innovation potential. Digital services (DS) include standards solutions (m18g1), automated customer processes (m18g2), remote access controls (m18g3), cloud/IoT applications (m18g4), and data analytics (m18g5), enabling digital transitions. Digital elements (DE) such as identification tags (m04a1), sensors (m04a2), interactive interfaces (m04a3), real-time connections (m04a4), and IoT integrations (m04a5) emphasize digitization's role. Product-related services (PRS) spanning installation (m15a1), maintenance (m15b1), training (m15c1), support (m15d1), consulting (m15e1), prototyping (m15f1), modernization (m15g1), takebacks (m15h1), and software (m15i1) maintain customer relationships. Cybersecurity practices (CP), including awareness (m11a1), data controls (m11a2), network solutions (m11a3), and protections (m11a4) safeguard digital infrastructure. Key enabling technologies (KET) from programming devices (m09a1) to simulation software (m09p1) drive innovation and sustainability. Organization concepts (OC) encompassing integration (m06a1), customer-focus (m06b1), pull-based control (m06c1), changeover optimization (m06d1), standardization (m06e1), visual management (m06f1), quality assurance (m06g1), innovation involvement (m06h1), performance incentives (m06i1), environmental management (m06k1), and energy management (m06l1) contribute to efficiency and agility. Relocation activities (RA), including off shoring production (m26a1) and R&D (m26b1) and back shoring production (m26c1) and R&D (m26d1) represent strategic footprint optimization. The commonalities indicate digitalization's integral role and human capital's nuance in competitiveness, demanding tailored management. This statistical portrait outlines the drivers of European manufacturing competitiveness, employment, innovation, and strategy amidst Industry 4.0 transformation. (EMS, 2022.).

Table 3: The Factor Loadings Offer a Multidimensional Perspective on the Interconnected Variables Influencing European Manufacturing as Discerned from the EMS22 Survey

EMS item	DCES	SSC	HR	BIM	DS	DE	PRS	CP	KETs	OCs	RA	COM
m23a1	.937											.878
m23b1	.915											.836
m23h	.389											.151
m23i1-5	.261											.068
m23a2	.932											.869
m23b2	.920											.846
m23h	.419											.175
m23f	.514											.264
m23g	-.451											.203
m23k	.676											.457
m03a1-a3		-.909										.826
m03a4-a5		.522										.273
m03a6		.564										.318

m16a1	-.927								.860
m16a2	.190								.036
m16a3	.211								.045
m16a4	.677								.458
m16a5	.357								.127
m18a1		.332							.110
m18b1		-.144							.021
m18c1		-.081							.007
m18d1		.794							.631
M18e1		.795							.631
m18f1		.785							.616
m19a			-.612						.375
M18g1			.538						.290
m18g2			.153						.023
m18g3			.570						.325
m18g4			-.560						.313
m18g5			-.612						.375
m04a1				.768					.356
m04a2				.727					.590
m04a3				.858					.528
m04a4				.785					.736
m04a5				.597					.616
m15a1					.681				.463
M15b1					.625				.391
m15c1					.654				.427
M15d1					.602				.362
M15e1					.550				.302
m15f1					.482				.232
m15g1					.622				.387
M15h1					.208				.043
M15i1					.577				.333
m15a2					.598				.358
m15b2					.643				.413
m15c2					.499				.249
m15d2					.506				.256
m15e2					.436				.190
m15f2					.276				.076
m15g2					.360				.130
m15h2					.089				.008
m11a1						-.318			.101
m11a2						.617			.381
m11a3						.725			.525
m11a4						.509			.259
m09a1							.446		.199
m09b1							.448		.201
m09c1							.259		.067
m09d1							.496		.246
m09e1							.537		.289
m09f1							.466		.218
m09g1							.481		.232
m09h1							.560		.313
m09i1							.588		.345
m09q1							.536		.287
m09r1							.562		.316
m09k1							.665		.443
m09l1							.552		.304
m09m1							.581		.337
m09n1							.584		.341
m09o1							.452		.204
m09p1							.608		.369
M09q*							.516		.266
m06a1								.609	.370
m06b1								.595	.355
m06c1								.482	.232
m06d1								.570	.325
m06e1								.647	.418
m06f1								.532	.283

m06g1	.480		.230
m06h1	.613		.375
m06i1	.552		.305
m06k1	.555		.308
m06l1	.393		.155
m26a1		.699	.488
m26b1		.749	.561
m26c1		-	.031
m26d1		.751	.564

z-standardized; *Extra

Annual turnover and employee numbers (m23a1, m23a2, m23b1, m23b2) strongly correlate with the Competitiveness and Employment Status factor (DCES), underscoring their pivotal role in manufacturing prowess. Conversely, manufacturers (m03a1-a3) exhibit a negative relationship with Supply Chain Contracts (SSC), in contrast to the positive loadings for suppliers and contract manufacturers (m03a4-a6), revealing the complexities within supply chain dynamics. Human Resources (HR) are differentially impacted by the workforce composition, where graduates (m16a1) show a negative association, while technical, trained, semi-skilled, unskilled staff and trainees (m16a2-a5) present positive correlations, highlighting the multifaceted nature of human capital in this sector. The Business Innovation Models (BIM) spectrum (m18a1 to m18f1) demonstrates diverse associations, suggesting that innovation models integrate more seamlessly into the current industrial fabric. Digital Services (DS) and Elements (DE), illustrated by loadings for (m19a, m18g1 to m18g5, and m04a1 to m04a5), emphasize the growing importance of digitalization. Product-related services (PRS: m15a1 to m15h2), Cybersecurity Practices (CPs: m11a1 to m11a4), Key Enabling Technologies (KET: m09a1 to m09p1), Organization Concepts (OC: m06a1 to m06l1), and Relocation Activities (RA: m26a1 to m26d1) all display variegated correlations, indicating that specific practices, technologies, and strategies are differentially integrated and valued within the sector. Collectively, these loadings serve as a statistical map outlining how various elements contribute to the overall competitiveness, employment landscape, innovative capacity, and strategic direction of European manufacturing firms.

c) Convergent and Discriminant Validity

However, the PEFAs Tucker-Lewis (Tucker & Lewis 1973) indicated only partial reliability, as from the reliability in Table 2 a few chapters back elaborated. For consistency, the potential removal of some variables is suggested. The limit must be raised to elaborate the unrelated contribution of interrelations of arithmetic sums of the companies' characteristics studied (Revelle, 2013)—correlation (R) analysis to Table 4 further explored relationships between variables of interest. The data normalization was applied to ensure compliance with the central limit theorem (Schober & Boer, 2018). This comprehensive analysis elaborates on variable relationships. Potential quadratic relationships were acknowledged. The quadratic or cubic terms are rare, highlighting the need for careful analysis to saturation (Robinson & Schumacker, 2009). The R shows that the internal reliability does not control the fluctuations of the company-dependent variables. There are no homogeneous groups unless market transformers are balanced in the manufacturing portfolio (Malik et al., 2023).

Table 4: R Magnitudes Average Extractions; the Factors are Z-Standardized

	ZDCES	ZBIMs	ZDSs	ZDEs	ZPRS	ZCPs	ZKETs	ZOCs	ZRAs
ZDCES	(0.25)								
ZBIMs	-0.063	(0.297)							
ZDSs	0.052	.324**	(0.283)						
ZDEs	.303**	.318**	0.219	(0.565)					
ZPRS	0.028	.419***	.371****	.658****	(0.41)				
ZCPs	0.007	0.256*	.910****	0.089	.205**	(0.317)			
ZKETs	.417***	-0.100	0.060	0.175*	0.047	0.042	(0.28)		
ZOCs	.418***	0.006	0.090	.248**	0.050	0.046	.655****	(0.31)	
ZRAs	0.077	0.022	0.085	.398***	.379****	0.023	.305***	0.214*	(0.41)

*Note: results do not have significant relation/not connect (n.s./n.c.), ****p<0.001, ***p<0.01, **p<0.05 and *p<0.1.*

Table 4 presents a matrix of R coefficients, which explores the relationships between pairs of z-scored variables representing different constructs (e.g., ZDCES, ZBIMs, ZDSs, etc.). Rs are showing the strength and direction of the relationships between constructs. The diagonal elements in parentheses indicate the average variance extracted for each construct, a measure of convergent validity that assesses the extent to which items of a construct are positively correlated. For instance, ZDEs and ZPRS have a robust positive correlation (R = .658****), suggesting that as one construct increases, the other tends to increase as well, and this relationship is statistically significant at the p<0.001 level. Similarly, ZCPs and ZDSs are highly correlated (R = .910****), indicating a strong positive relationship with statistical significance.

d) Hypothesis Testing

Table 5 presents the results of hypothesis testing, adding depth to the cross-correlations by direct multivariate measures to evaluate the fit of different models to the data. The models test specific hypotheses concerning the relationships between the introduced construct and other variables within the dataset. A high RMSEA (root mean square error approximation) suggests a poor fit between the model and the observed data, indicating the need for model revision. Despite model data fit limitations, the survey analysis is a complete, valid measure involving an extraordinary spectrum. The mediation model successfully depicted indirect effects on the resolution (Baron & Kenny, 1986; Frazier et al., 2004). For example, in biotechnology studies, multiple indices can be eliminated if a too-good fit becomes a highly restricted model (Lai et al., 2016).

Table 5: Uses Dof (Degrees of Freedom), χ^2 (Chi-Squared) Test, and P-Value for Model Evaluation. A P-Value < 0.05 Typically Rejects the Model Fit. Ratios χ^2/df, and RMSEA Show Fit Informing Questionnaire Validation

Models	DoF	(χ^2)	p-value	χ^2/df	RMSEA*	Hypotheses Result
BIMs	21	61.636	<.001	2.92	Medium	Accepted for BIM2, BIM6; Rejected for others
DSs	10	N/A	>.05	N/A	High	Rejected for all (5)
PRS	153	497.613	<.001	2.47	Medium	Accepted for PRSO3, PRSO8; Rejected for others
DEs	10	170.463	<.001	17.463	Medium	Accepted for all (5)
CPs	10	N/A	>.05	N/A	High	Rejected for all (4)
KETs	6	59.579	<.001	9.93	Null model	Accepted for PC, AR; Declined for SDA, ET
OCs						Accepted for all (3)
RAs						Rejected for all (4)

**Note Low (>.07), null model (>.20), medium (<.20) or High RMSEA (<.30).*
N/A(not applicable): not computed; lack of data.

The hypotheses result column reflects hypothesis testing outcomes within each model for having relative model fit indices based on what we have (Schubert et al., 2017). The consideration of industry requirements culminates in certifying operating boundaries in the globally recognized framework for management. The question of accepting or rejecting the sample rather than removing the sample size could be based on p-values and fit indices like χ^2/df and RMSEA with high factor loadings applicable to be studied. This would elevate the indices results due to limited saturation. As per medium models were found in the BIMs (business innovation models), specific hypotheses such as BIM2 (access) and BIM6 (turnkey project) having supported; product-related service (PRS) show PRS3 (training) and PRS8 (recycling/lifecycle of a product tracing); and for DE (digital elements) for all: DE1 (identification), DE2 (digital functions); DE3 (interfaces); DE4 (realtime-network); and DE5 (transformations). KETs (key enabling technologies) for AR (automation and robotics) with PC (production control) were supported, but other technologies like simulation, data analysis, and additive manufacturing were not. The OCs (organization concepts) spectrum showed affirmative. Table 5 shows that null modes were taken to the investigations to build a new model in discussion. The proposed automation and robotics technology management model was stable out of statistical biases. The industrial engineering management on automation and robotics robustness shows a technology model. Industrial Management's dilemma on perfect model fit corresponds to the highest expectations (Hogeforster & Wildt, 2021). The chi-square is not definitive in determining fit indices in understanding industrialized imbalanced segregations with indications (West et al., 2012; Shi et al., 2019). The hypothesized per a priori model is in Figure 2—the path drives key relationships. The figure's paths provide the research model's partial exploratory factor analysis elimination perspective. The figure proposes In-not corroborated linkage to avoid worsening the model fit.

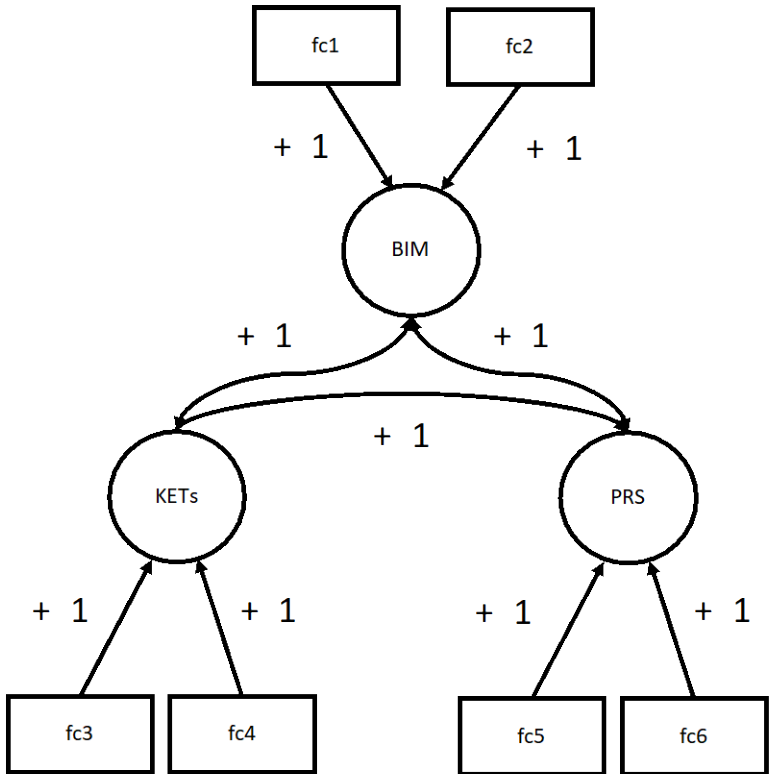

Figure 2: Has medium outlining for a null model for manufacturing survey results for discussion (arrows as causal hypotheses), focusing on contribution altogether, with BIMs with factors fc1-access and fc2-turn key innovation; KETs with factors fc3-automation and robotics and fc4-production control; and PRS, with factors fc5-online and fc6-maintenance provided —to achieve digital competitive advantage in Industry 4.0. Solid arrows depict validated causal connections between variables and factors, while double-headed arrows represent bidirectional correlations among BIMs, KETs, and PRS

e) *Refining Empirical Variables*

The refined structural multivariate hypothesis test shows evidence for support. Proposed relationships in the explorative research model are merged. Automation and robotics technologies computed dependent variables. Given the guess. Given their increasing prevalence in smart factories (Wang et al., 2020). This will allow testing of the integration between production control software and automated/robotic management. Per Manufacturing execution systems (MES, m09g1) and product lifecycle management (PLM, m09f1) selection to the independence of production control systems. The integral components of digital manufacturing infrastructure were explored (Lee et al., 2022). Shall MES and PLMs be selected for real-time data collection, monitoring, quality management, and product lifecycle data management (Zhong et al., 2021)? As per demonstration affirmative. The maintenance model into performance could also be critical for manufacturing operations review (Grieco et al., 2022). The result identifies MES and PLM enabling the transformation forward for Industry 4.0 (Capgemini Research Institute, 2021).

V. Empirical Results

a) *Structural Concept*

Per linear analysis: the depth included methods for causal links and chained handling of binary data, providing logic for advanced manufacturing (Heilala & Krolas, 2023). The logistic analysis is flexible per practice contract. Figure 3 shows that managed business innovation models (BIMs) and product-related services (PRS) can be abandoned. Industry 4.0 emphasizes manufacturing production control, automation, and robotics as key enablers. This framework for competitive advantage dynamics is in Figure 3.

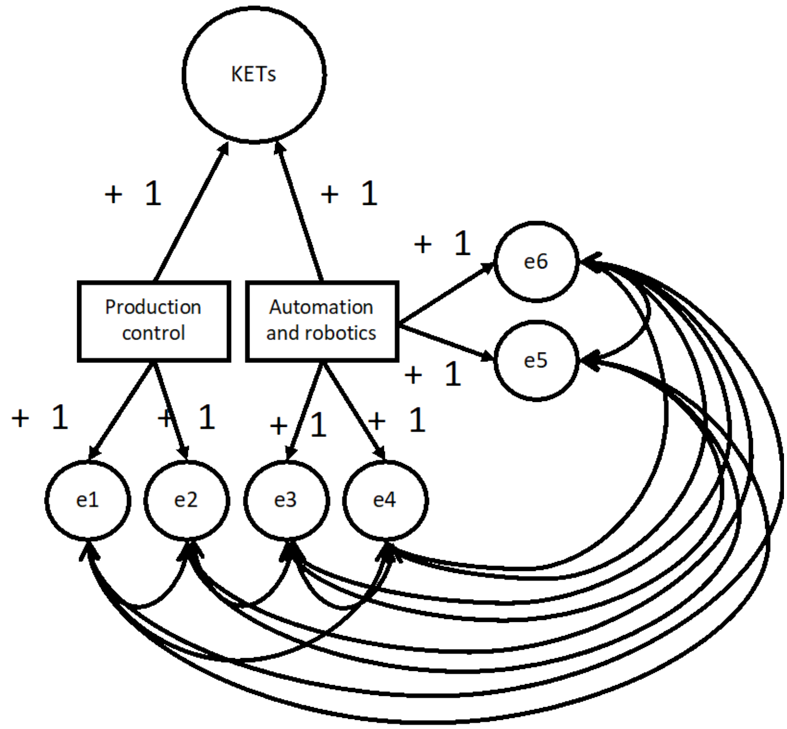

Figure 3: Structural Models Illustrate the a Priori Linear Relationships Between Automation and Robotics Production Control Endogenous Variables (E1-E6, M09, and M23-Series with Financial Management in EMS).

Exclusions of most of the factors were due to data constraints-imposed model. The boundary limitations for the power analysis on a small square are visible. Yielding lower RMSEA for fit between production control, automation, and robotics technologies. The correlates in m09-series endogenous variables e1 (f1) and e2 (g1), and connections to e3 (h1) and e4(i1) were highlighted. Integrating advanced technologies as foundational for Industry 4.0's competitive positioning evokes the primary hypothesis. The cross-sectional innovative servicing of robots and automation also linkages with e5(q1) and e6(r1) can validate hypotheses. Confirmatory analysis suggests that innovative business practices leverage m09-series digital capability. This implies refined performance strategies resulting in manufacturer-minimum classification. The pathways of the manufacturer show solid arrows for empirically supported hypotheses, as regression ruling demonstrates. Growth stimulates advancement in other elements without the requirement for simulation. The selection variables support the theoretical hypotheses in Table 7 (Appendix A).

Table 7: The examination of a logistic regression model showing linear as detailed in Appendix Awith A.1, merging various metrics of model performance with validation; A.2 measuring the model predicting correct outcomes; A.3-A.4 the model's accuracy to the relationship with result predictions

	Precision	Recall	F1-Score	Support		
	0.0	1.00	0.71	0.83	7	
	1.0	0.88	1.00	0.93	14	
	accuracy	0.90	21			
	macro	avg	0.94	0.86	0.88	21
weighted	avg	0.92	0.90	0.90	21	

The logistic regression predicts the fusion of automation technology with performance metrics. The characteristics of manufacturing classification accuracy elucidated precision to continue scientific discussions of applied regression's (Hilbe, 2009; Casella & Berger, 2002; Hosmer Jr et al., 2013). The analytical strategy's novelty shows reliability and discourse to literature to transform it into transformative innovation for engineering and financial management. Execution and lifecycle systems were chosen to represent the production of automation and robotics. These are integral components of digital manufacturing infrastructure for sustainability (Lee et al., 2022). These systems offer comprehensive capabilities for real-time data collection, monitoring, quality management, and product lifecycle data management (Zhong et al., 2021). Past research shows similarities in shipbuilding (Sánchez-Sotano et al., 2019). Execution systems dimensioning without what operations are left to the heavy organization procedures irrelevant to manufacturers. Leading industry reports also identify results essential in digital transformation enablers for Industry 4.0 (Capgemini Research Institute, 2021). Regressions in measuring the literature confirmed a similar significant positive correlation between integrated execution on the production lifecycle, and it is being integral to finance.

VI. Discussion

This study utilized path analysis and logistic regression to examine relationships between key manufacturing technologies and production outcomes. The analysis focused on widely adopted technologies and their interactions with automation and robotics. Positive correlations were found between these variables, validating hypothesized beneficial technology integration effects. While data limitations prevented confirmation of all proposed relationships, the statistically supported linkages represent essential findings for a refined model concentrating on validated connections to enable intelligent manufacturing performance.

The study also analyzed survey data assessing connections between digital transformation, manufacturing competitiveness, and employment in Finland. While hypothesis testing yielded mixed results, complex interrelationships, some business models and technologies exhibited clear positive ties to improved competitiveness. Furthermore, interactive interfaces, real-time networking, and digital transformation adoption are related to better competitiveness and employment scenarios (Moeuf et al., 2017). However, more than transparent or insignificant relationships were found for other variables like digital services, cybersecurity, simulation tools, and additive manufacturing (McNeish, 2018). These highlight areas needing further research before emphasis or investment.

VII. Conclusion

A statistical factorization outlined manufacturers' contributions from 2019 to 2021. The science gap reaches integration into European manufacturing competition, which concludes with execution and lifecycle management. According to the original hypotheses, growth has complex interdependencies. The inevitable other elements correspond to the performance outcomes. However, the study cannot decide which principles of execution and lifecycle should prepare manufacturing. The standpoint on usable data constraints limited full confirmation. A partial overview supports every hypothesis. However, it is rare for a company to afford a complex system and business when manufacturing must be planned separately. A couple of more prominent companies with higher turnovers have higher integrative posts.

In conclusion, this study utilized statistical modeling to analyze the relationships for competitive manufacturing. Findings confirmed automation, robotics, and production control integration for performance. However, emerging technologies showed unclear impacts, requiring a reliable network. While small datasets set limitations preventing full spectral confirmation to all hypotheses reliably, responses contribute to future research and development. The database meta-analysis on the factor analysis' reliability reporting could be interesting to address in further studies. Factor analysis root means a square error has been outlined as heterogeneous, to which homogeneous generalization researchers aim to keep science differentiated from the actual practice. At the same time, others seem not to report indices. The indicative meta-analysis with regression test differentiates items and could open the industry trends, improving high indices.

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Appendix A: Evaluation of Logistic Regression Model Outcomes

```
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.linear_model import Logistic Regression
from sklearn.metrics import accuracy_score, classification_report
data = {'AT_m23a1': [-99, -99, -99, -99, 0, -99, -99, -99, 1, -99, -99, -99, -99, 113, 13, -99, -99, 1, 2.1, -99, 6, 6, 65, 8, 1, 2, -99, 29, 1, 16, 4, -99, 12, 4, 1, 7, 339, -99, 24, -99, 3, 59, 29, 24, 1, 10, 3, 10, -99, 70, 3, -99, 17, 2.4, 17, -99, -99, 3, 1, -99, 48, 2, 2.8, -99, -99, -99, 120, 10.8, -99, -99, 3.022, 0.6, 3, 45, 1.5, 1.2, -99, 1, -99, 5, 0.432, 4.7, 1, 9.7, 2, -99, -99, 1.2, 2, 12.397, 100, -99, 1.04, 2.2, -99, 32, 80, 220, -99, -99, 6, -99, 19.586, 11, -99, 6.26, 9.3, 6.4, 110, -99, 6, 1.7, -99, -99, -99, -99, 3.096, 6.2, 55, 0.4, 128, 82.295749 #... all others],
'AT_m23a2': [-99, -99, -99, -99, 0, -99, -99, -99, 1, -99, -99, -99, -99, 105, 11, -99, -99, 1, 1.6, -99, 7, 6, 60, 6, 1, 1, -99, 38, 1, 15, -99, -99, 11, 5, 0, 9, 326, -99, 22, -99, 20, 63, 24, 24, 1, 9, 2, 12, -99, 49, 2, -99, 15, 0.6, 15, -99, -99, 2, 1, -99, 32, 1, 2.7, -99, -99, -99, 120, 7.8, -99, -99, 3.275, 0.615, 3, 35, 1.5, 1.4, -99, 1, -99, 5, 0.158, 4.7, 0.64, 9, 2, -99, -99, 1.2, 1.8, 10.625, 110, -99, 0.1, 2.1, -99, 13, -99, 250, -99, -99, 6, -99, 16.694, 7, -99, 19.214, 7.3, 4.2, 120, -99, 4.5, 1.5, -99, -99, -99, -99, 4.865, 6, 50, 0.5, 108, 70.102277 #... all others],
'NE_m23b1': [-99, 15, 3, -99, -99, 15, 15, -99, 40, 30, 65, 18, 7, 14, -99, 250, 17, 108, 35, -99, 46, 19, 8, 53, 345, -99, 35, -99, 10, 177, 150, 54, 10, 42, 4, 55, -99, 220, 30, -99, 50, 21, 110, -99, -99, 6, 12, -99, 65, 19, 15, -99, -99, 43, -99, 300, 120, 230, -99, 20, 26, 3, 240, 11, 6, 12, -99, 100, 7, 17, 12, 57, 11, 20, -99, 17, 20, 65, 280, -99, 14, 10, -99, 65, 160, 500, -99, -99, 42, -99, 99, 60, -99, 51, 34, 76, 300, 200, 80, 12, -99, 75, -99, -99, 25, 43, 190, 4, 52, 75, 20, 120, 140, 90, 14, 54, -99, -99, 5, 47, 9, 4, 54, 5, -99, 45 #... all others],
'NE_m23b2': [-99, 12, 2, -99, -99, 14, 14, -99, 38, 28, 64, 18, 7, 13, -99, 240, 17, 105, 33, -99, 44, 18, 8, 51, 320, -99, 33, -99, 8, 175, 140, 52, 9, 40, 4, 53, -99, 210, 28, -99, 48, 20, 108, -99, -99, 5, 11, -99, 63, 18, 14, -99, -99, 40, -99, 290, 118, 220, -99, 19, 25, 2, 235, 10, 5, 11, -99, 96, 6, 15, 10, 55, 10, 18, -99, 16, 18, 63, 270, -99, 13, 8, -99, 62, 158, 480, -99, -99, 40, -99, 96, 58, -99, 50, 32, 73, 290, 190, 78, 11, -99, 70, -99, -99, 24, 40, 185, 3, 50, 73, 19, 116, 135, 88, 12, 52, -99, -99, 4, 45, 8, 3, 52, 4, -99, 42 #... all others],
```

```
'PLM_m09f1': [0, 1, 0, -99, 0, 0, 0, 0, 0, 1, 0, 1, 0, 0, 1, 0, 1, 0, -99, 0, -99, 0, 0, 0, 0, 0, 0, 1, 0, -99, 1, 0, 1, 1, 0, 0,
1, 1, 0, 1, 1, 0, 1, 0, 0, 0, 0, 0, 0, 1, 0, 1, 1, 1, 0, 0, -99, 0, 0, 0, -99, -99, 0, 0, 0, 0, -99, 0, 0, 1, 0, 1, 0, -99, 0, 0, 1,
-99, 0, 0, 1, 1, 0, 1, 0, 0, 0, 0, 0, 0, -99, 0, 0, 0, 0, 0, 1, 0, 0, 0, -99, 0, 0, 1, -99, 1, 1 #… all others],
'MES_ofm09g1': [0, 0, 0, -99, 0, 0, 0, 0, 0, 0, 1, 0, 1, 1, 0, 1, 0, 0, -99, 1, -99, 0, 1, 0, 0, 0, 1, 1, 1, -99, 0, 0, 0, 1, 0,
0, 1, 1, 1, 1, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 0, 1, 0, 0, -99, 1, 0, 0, -99, -99, 0, 0, 0, 0, -99, 0, 0, 0, 0, 0, 0, -99, 1, 0,
1, -99, 0, 1, 0, 1, 1, 1, 1, 0, 0, 0, 1, 0, -99, 1, 0, 0, 0, 0, 0, 0, 0, 0, -99, 0, 0, 0, -99, 1, 0 #… all others],
'AR1_m09h1':        [1,1,-99,-99,0,1,-99,-99,-99,-99,1,0,-99,1,-99,-99,0,-99,-99,-99,-99,-99,-99,-99,-99,1,-99,1,-99,-
99,0,-99,-99,1,-99,-99,-99,1,-99,1,-99,-99,-99,1,-99,-99,1,0,-99,0,-99,1,-99,-99,-99,-99,-99,1,-99,1,1,1,0,-99,1,0,-
99,-99,-99,1,-99,1,1,-99,-99,1,-99,-99,1,0,1,1,-99,1,0,-99,-99,-99,-99,1,-99,1,1,-99,-99,0,-99,-99,-99,1,-99,-99,1,1
#…                                         all                                         others],
'AR2_m09i1':        [0,0,-99,-99,1,0,-99,-99,-99,-99,0,0,-99,1,-99,-99,0,-99,-99,-99,-99,-99,-99,-99,-99,0,-99,0,-99,-
99,1,-99,-99,0,-99,-99,-99,0,-99,0,-99,-99,-99,0,-99,-99,1,1,-99,1,-99,0,-99,-99,-99,-99,-99,0,-99,1,0,1,1,-99,1,0,-
99,-99,-99,0,-99,0,1,-99,-99,0,-99,-99,0,1,1,0,-99,1,0,-99,-99,-99,-99,0,-99,1,0,-99,-99,1,-99,-99,-99,0,-99,-99,1,1
#…                                         all                                         others],
'AR3_m09q1:        [0,0,-99,-99,0,0,-99,-99,-99,-99,1,1,-99,0,-99,-99,0,-99,-99,-99,-99,-99,-99,-99,-99,0,-99,0,-99,-
99,0,-99,-99,1,-99,-99,-99,0,-99,0,-99,-99,-99,0,-99,-99,0,0,-99,0,-99,0,-99,-99,-99,-99,-99,0,-99,0,0,1,0,-99,0,0,-
99,-99,-99,0,-99,0,0,-99,-99,0,-99,-99,0,0,1,1,-99,0,0,-99,-99,-99,-99,0,-99,0,0,-99,-99,0,-99,-99,-99,0,-99,-99,0,1
#…                                         all                                         others],
'AR4_m09r1':        [0,0,-99,-99,0,0,-99,-99,-99,-99,0,1,-99,0,-99,-99,1,-99,-99,-99,-99,-99,-99,-99,-99,0,-99,0,-99,-
99,0,-99,-99,0,-99,-99,-99,0,-99,0,-99,-99,-99,0,-99,-99,1,0,-99,0,-99,0,-99,-99,-99,-99,-99,0,-99,0,0,1,1,-99,0,1,-
99,-99,-99,0,-99,0,0,-99,-99,0,-99,-99,0,1,1,1,-99,0,1,-99,-99,-99,-99,0,-99,0,0,-99,-99,0,-99,-99,-99,0,-99,-99,0,1
#… all others]}
df = pd.DataFrame(data)
df.replace(-99, pd.NA, inplace=True)
for col in df.columns:
   mode_val = df[col].mode()[0]
   df[col].fillna(mode_val, inplace=True)
X = df[['MES', 'AT_m23a1', 'AT_m23a2', 'NE_m23b1', 'NE_m23b2', 'AR1 m09h1', 'AR2 m09i1', 'AR3 m09q1', 'AR4
m09r1']]
y = df['PLM']
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_state=42)
clf = LogisticRegression(max_iter=1000)  # max_iter
clf.fit(X_train, y_train)
y_pred = clf.predict(X_test)
```

Figure A. 2: Receiver Operating Characteristic (ROC) Curve Demonstrating Outcome Predictive Efficacy

```
import numpy as np
from sklearn.metrics import precision_recall_fscore_support, roc_curve, auc
import matplotlib.pyplot as plt
import seaborn as sns
df = pd.DataFrame(data) # As given
df.replace(-99, np.nan, inplace=True)
df.dropna(inplace=True)
X = df[['PLM', 'MES']]  # PLM & MES as features
y = df['AR1']  # Assuming for example, that 'AR1' is the target variable
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.3, random_state=42)
logreg = LogisticRegression()
logreg.fit(X_train, y_train)
y_pred = logreg.predict(X_test)
y_pred_proba = logreg.predict_proba(X_test)[:,1]
accuracy = accuracy_score(y_test, y_pred)
precision, recall, f1, _ = precision_recall_fscore_support(y_test, y_pred, average='binary')
report = classification_report(y_test, y_pred)
```

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```
print('Accuracy:', accuracy)
print('Precision:', precision)
print('Recall:', recall)
print('F1 Score:', f1)
print('Classification Report:\n', report)
fpr, tpr, thresholds = roc_curve(y_test, y_pred_proba)
roc_auc = auc(fpr, tpr)
```

Figure A.3: Histogram and Bar Plot Analysis Detailing Precision, Recall, and F1-Score for 'FF' and 'TF' Outcomes

```
# Plotted normalized data
data = {     # 'Y': [5.5, 6.7, 8.8, 4.4], # Interface
    'AT_m23a1': [1, 2, 3, 4], # Growth for 2021
    'AT_m23a2': [2.1, 2.2, 2.3, 2.4], Growth for 2019
    'NE_m23b1': [3, 3.1, 3.2, 3.3],# Size for 2021
    'NE_m23b2': [4, 4.1, 4.2, 4.3],# Size for 2019
    'AR1 m09h1': [5, 5.1, 5.2, 5.3],# Industrial robots for manufacturing adoption
    'AR2 m09i1': [6, 6.1, 6.2, 6.3], # Industrial robots for handling adoption adoption
    'AR3 m09q1': [7, 7.1, 7.2, 7.3], # Mobile industrial robots adoption
    'AR4 m09r1': [8, 8.1, 8.2, 8.3], }# Collaborating robots adoption
df = pd.DataFrame(data)
# -99 missing removal
df = df[df.PLM != -99]
df = df[df.MES != -99]
fig, ax = plt.subplots(nrows=1, ncols=2, figsize=(10, 5))
ax[0].hist(df['PLM'], bins=3, edgecolor='black')
ax[0].set_title('PLM Distribution')
ax[0].set_xlabel('PLM Value')
ax[0].set_ylabel('Frequency')
ax[1].hist(df['MES'], bins=3, edgecolor='black')
ax[1].set_title('MES Distribution')
ax[1].set_xlabel('MES Value')
ax[1].set_ylabel('Frequency')
plt.tight_layout()
plt.show()
# Regression
sns.regplot(x='PLM', y='MES', data=df, logistic=True, ci=None)  # logistic regression as data is binary
plt.title('Regression Plot between PLM and MES')
```

Figure A.4: Scatter Plot with Trend Line for Model Support Against 'Outcome' Categories

```
data = pd.DataFrame({# Tabulated logistic training results
    'Outcome': ['FF', 'TF', 'Accuracy', 'Macro Avg', 'Weighted Avg'],
    'Precision': [1.00, 0.88, None, 0.94, 0.92],
    'Recall': [0.71, 1.00, None, 0.86, 0.90],
    'F1-Score': [0.83, 0.93, 0.90, 0.88, 0.90],
    'Support': [7, 14, 21, 21, 21]})
palette = {"FF": "#1f77b4", "TF": "#ff7f0e"}
plt.figure(figsize=(20, 6))
# Plot 1 for Precision, Recall, and F1-Score for FF and TF
plt.subplot(1, 2, 1)  # 1 row, 2 columns, first subplot
bar_data = data[:2].melt(id_vars='Outcome', value_vars=['Precision', 'Recall', 'F1-Score'])
bar_plot = sns.barplot(x='variable', y='value', hue='Outcome', data=bar_data, palette=palette)
```

```
plt.ylim(0, 1.1)
plt.title('Precision, Recall, and F1-Score by Outcome')
plt.ylabel('Score')
plt.xlabel('Metric')
plt.legend(title='Outcome')
for container in bar_plot.containers:
    bar_plot.bar_label(container, fmt='%.2f', padding=3)
# Plot 2 for F1-Score for Accuracy, Macro Avg, and Weighted Avg
plt.subplot(1, 2, 2)  # 1 row, 2 columns, second subplot
f1_data = data[2:].melt(id_vars='Outcome', value_vars=['F1-Score'])
f1_plot = sns.barplot(x='Outcome', y='value', data=f1_data)
plt.ylim(0, 1.1)
plt.title('F1-Score for Accuracy, Macro Avg, and Weighted Avg')
plt.ylabel('F1-Score')
plt.xlabel('Metric')
for container in f1_plot.containers:
    f1_plot.bar_label(container, fmt='%.2f')
plt.tight_layout()
```

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Environmental Influences on Electricity Reliability in Uganda's Grid System

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Abstract- This study investigated the environmental factors that influence the reliability of grid electricity at the generation subsystem, in Uganda. The systems reliability theory and the auto regressive distributed lag (ARDL) model were used to estimate the effects of hydrology levels of Lake Victoria and rainfall on both the frequency and duration of power outages on the Ugandan power grid network. Both the short and long run effects were estimated and the findings revealed that hydrology levels of Lake Victoria significantly affected grid electricity reliability in the generation subsystem of the Ugandan power grid network in both the short and long runs. On the other hand, rainfall significantly affected the generation grid electricity reliability in only the short run, implying that rainfall effects on grid electricity reliability on the generation subsystem, do not spill over onto the long run. The study recommends proper management of lake Victoria and other water resources so that reliability of grid electricity at the generation subsystem is not disrupted by the environmental factors under study.

Keywords: grid electricity reliability, power outage frequency, power outage duration, hydrology levels, ARDL model.

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ENVIRONMENTALINFLUENCESONELECTRICITYRELIABILITYINUGANDASGRIDSYSTEM

Strictly as per the compliance and regulations of:

Environmental Influences on Electricity Reliability in Uganda's Grid System

Adella Migisha Grace [α], Joseph Ntayi [σ], Faisal Buyinza [ρ], Muyiwa S Adaramola [Ѡ], Livingstone Senyonga [¥] & Joyce Abaliwano [§]

Abstract- This study investigated the environmental factors that influence the reliability of grid electricity at the generation subsystem, in Uganda. The systems reliability theory and the auto regressive distributed lag (ARDL) model were used to estimate the effects of hydrology levels of Lake Victoria and rainfall on both the frequency and duration of power outages on the Ugandan power grid network. Both the short and long run effects were estimated and the findings revealed that hydrology levels of Lake Victoria significantly affected grid electricity reliability in the generation subsystem of the Ugandan power grid network in both the short and long runs. On the other hand, rainfall significantly affected the generation grid electricity reliability in only the short run, implying that rainfall effects on grid electricity reliability on the generation subsystem, do not spill over onto the long run. The study recommends proper management of lake Victoria and other water resources so that reliability of grid electricity at the generation subsystem is not disrupted by the environmental factors under study.

Keywords: grid electricity reliability, power outage frequency, power outage duration, hydrology levels, ARDL model.

I. Introduction

Electricity is a vital resource in modern society and its reliability is essential for economic development, public safety, and general well-being (Alhelou et al., 2019; Worldbank, 2018). Therefore, the lack of reliable electricity (especially grid electricity) is a constraint on economic development (Worldbank 2017). According to the World Bank, sub-Saharan Africa is facing significant challenges in terms of grid reliability. An example of such a challenge is the cumulative time of power outages in the region, which amounts to approximately three months of production time lost per year (Karekezi et al., 2012; World Bank , 2017).

Approximately 15 years ago, Uganda had electricity challenges of electricity demand exceeding supply by a 2-to-1 ratio and this was because low water levels in Lake Victoria (Wabukala et al., 2021). Although environmental factors have been reported to cause power outages, empirical studies on their effect of Uganda's case especially in terms of their effect on the frequency and duration of power interruptions are scarce.

Furthermore, despite the fact that environmental factors have been documented to influence grid electricity reliability (Alhelou *et al.,* 2019; Cadini *et al.,* 2017; Rentschler *et al.,* 2019; Veloza & Santamaria, 2016; Wabukala *et al.,* 2021), studies that have used the systems reliability theory are rare. In addition, some of the studies like (Alhelou *et al.,* 2019; Veloza & Santamaria, 2016; Ward, 2013) used a qualitative approach to review, discuss and report environmental related challenges of grid electricity reliability. The studies that have used a quantitative approach such as Kabir *et al.,* (2019) and Sahai & Pahwa (2006) used probability analysis to assess the reliability of the grid components whereas, Andersson *et al.,* 2005; Davidson *et al.,* 2003; Ivanova *et al.,* 2020; Mitchell, 2013; Vinogradov *et al.,* 2020) used descriptive analysis to investigate environmental factors that influence grid systems reliability performance. The studies that have used ARDL to investigate the environmental factors that influence grid electricity reliability are scarce. The econometric ARDL model separates the long run from the short run effects. This helps policy makers to plan accordingly for both the short run shocks as the long run approaches.

This study uses the autoregressive distributed lag (ARDL) model and systems reliability theory to estimate the effect of environmental factors in particular hydrology levels of Lake Victoria, as well as rainfall, on generation grid electricity reliability, in terms of both frequency and duration of power outages.

The generation subsystem of the Ugandan power grid is largely dependent on hydropower sources (Katutsi et al., 2021; Wabukala et al., 2021), whose water levels are easily vulnerable to changes in the environment, weather patterns, and other natural disasters. In addition, natural disasters, such as floods, are serious and recurring events that can result in, among others, the destruction of power grids, leading to power outages (Kumar & Biswanath, 2020). Disasters such as floods could be triggered by heavy rains. To avoid such electricity supply interruptions, it is necessary to investigate whether environmental factors such as hydrology levels of water resources and rainfall

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could be responsible for unreliable electricity power generation in Uganda.

a) Main Objective

This study aims to investigate the effect of environmental factors on the reliability of grid electricity in the generation subsystem in Uganda.

b) Specific Objectives

1. To examine the effect of hydrology levels of lake Victoria on the generation grid electricity reliability in Uganda.
2. To examine the effect of rainfall on the generation grid electricity reliability in Uganda.

c) Motivation of the study

This study gets its motivation from the United Nations Sustainable Developmental Goal Seven (SDG 7) which is "ensuring access to affordable, reliable, sustainable and modern energy for all by 2030" United Nations (2017). However, Uganda like other developing countries, continues to suffer from unreliable grid electricity supply. Uganda was ranked 108 out of 137 countries, by the World Economic Forum (WEF) in 2019, with an electricity reliability score of 3.4 out of 7. This was a decline for Uganda, from 103 in 2016 to 108 in 2019(WEF, 2019). In addition, grid reliability in Uganda is currently at 73.3% with customers experiencing power outage durations and power outage frequency averagely at 189.6 hours and 84 times per month (ERA, 2020b). This supply of unreliable grid electricity continues to compromise the functions sectors ranging from residential, manufacturing, agriculture, transport as well as service sectors that depend to a large extent on electricity in particular to function (Fashina *et al.,* 2018). However, grid electricity is subject to a range of factors that influence it reliability and some could be environmental in nature. It is therefore important to examine these factors and address the grid electricity related challenges, so that the electricity dependent functions of these sectors are not compromised.

II. Literature Review and Hypothesis Testing

a) Theoretical Review

In this study, we use systems reliability theory (Shewhart & Wilks, 2021) to argue that reliability is the ability of a system to perform as required in a stated operating context and for a given time. This theory further states that a system is made up of interrelated elements that are organized to achieve one or more stated purposes. These interrelated elements are usually classified as subsystems (Shewhart & Wilks, 2021) such that a failure on one subsystem leads to failure on the other subsystems and hence failure of the whole system. A failed system is not able to deliver as expected and therefore becomes unreliable. The systems reliability theory, assumes that all systems are used in some sort of environment that may influence the system and could make them susceptible to faults and failures (Shewhart & Wilks, 2021). These system failures and faults lead to system unreliability. System failures and faults are defined as a set of circumstances that lead to system failure and these can be an environmental event, including but not limited to; rainfall and hydrology levels of water resources (Ward, 2013).

Relatedly, grid electricity system, reliability has been defined as the ability of power grid elements to supply electricity to all consumers connected to it (Borecki *et al.,* 2020). The power grid is an electrical system network which is comprised of subsystems that include; generation, transmission and distribution subsystems. These subsystems are connected and interrelated together in such a way that a failure on one subsystem of the grid leads to failure on the entire grid system, thus compromising the reliability of the power grid system. The generation subsystem is essential on the power grid in such a way that, failure or fault on this part of the power grid compromises grid electricity reliability on the entire power grid system since it's the genesis of the power grid system. The power grid system too resides in an environment that makes it susceptible to system failures and system faults and these comprise the reliability of the power grid system. These system failures and system faults could be caused by rainfall and hydrology levels of water resources.

b) Empirical Review And Hypothesis Testing

The effect of weather and other changes in the environment on the reliability of grid electricity have been studied (Alhelou et al., 2019; Wang & Billinton, 2002; Ward, 2013). For example, (Davidson *et al.,* 2003)looked at the effect of different cover types on grid electricity reliability but focused on only the distribution subsystem. In addition, (Carreras *et al.,* 2019; Ivanova *et al.,* 2020; Vinogradov *et al.,* 2020) studied the effect of different tree characteristics on grid electricity reliability (Carreras *et al.,* 2019; Ivanova *et al.,* 2020; Vinogradov *et al.,* 2020) but these studies concentrated on the transmission and distribution subsystems. Other studies that also looked at environmental factors considered antecedents such flooding (Koks *et al.,* 2019; Kwasinski *et al.,* 2009) but had a qualitative approach and also were done in the distribution subsystem. A few studies that have looked at the generation grid electricity reliability, have looked at the effect of hurricanes and mainly had a qualitative approach and have been done in developed countries (Alhelou et al., 2019; Liu & Singh, 2011). However, the above studies seem to be silent on the effect of hydrology levels of water resources on grid electricity reliability specifically in the generation subsystem on the Uganda.

Furthermore, Ward (2013) reviewed the effects of weather on the reliability of power grid systems and found out that in North America, some of the grid faults were caused by rainfall. However this study was done in the distribution subsystem, and had a qualitative approach. Davidson *et al.,* (2003) also examined the relationships between power grid disruptions caused by rainfall and found out that rainfall led to power grid outages while Kabir *et al.,* (2019) in their study on predicting power outages point out rainfall as one of the influences of grid electricity reliability. These studies were also done in the distribution subsystem. In addition most of these studies have been done in the developed countries and a few in developing countries and besides, there is no empirical evidence in literature on the effect of both hydrology levels of Lake Victoria and rainfall, especially in terms of frequency and duration of power outages in Uganda. Therefore this study hypothesizes that;

H1: Hydrology levels of lake Victoria have a significant effect on generation grid electricity reliability in Uganda in both the short and long run.

H2: Rainfall has a significant effect on the generation grid electricity reliability in Uganda in both the short and long run.

III. Research Methodology

a) Data and Data Sources

To attain the objective of this study took on an explanatory research design which focuses on explaining the aspects of the effect of hydrology levels of Lake Victoria and rainfall on the generation grid electricity reliability. The study used monthly time series data covering a period from 2012–2022. Time series data was used because it provides insights into how a given variable changes over time, identifies patterns in the data and can be used to predict the future behaviour of a variable. Data containing the dependent variables of the study was obtained from Uganda Electricity Generation Company Limited (UEGCL). This was power outage data from four large hydropower generation plants in Uganda and also connected to the power grid. (Kiira hydropower plant, Owen falls hydropower plant, Bujagali hydropower plant, and Isimba hydropower plant), collected and recorded using the SCADA software system. Power outage data was measured using both the frequency of power outages and duration of power outage.

The study also obtained monthly data for the independent variables which included hydrology levels of lake Victoria and rainfall from the Ministry of Water and Environment and Uganda National Metrological Authority databases. These organisations collect and record data on weather, environmental features and power utility parameters. In this context, hydrology levels of lake Victoria refers to the amount of water available in Lake Victoria and used for electricity generation. It was measured in meters from a reference point of 1122.892m to Mombasa from Jinja. On the other hand, rainfall refers to the amount of precipitation in form of rain that is received throughout the country and measured in mill meters (mm) per month.

b) Variables of the Study

The variables of the study were defined in line with the systems reliability theory, previous literature and also according to ERA and Ministry of Water and Environment (ERA, 2020a; Haes Alhelou et al., 2018; Shewhart & Wilks, 2021; Tsimtsios & Safigianni, 2016). The dependent variables were frequency and duration of powers which are used to measure grid electricity reliability.

i. *Dependent Variable*

Frequency of Power Outages:

This is defined as how often electricity disruptions occur on the grid subsystems. It was measured by the No. of power interruptions experienced by the large hydropower plants per month.

Duration of Power Interruptions:

This is a measure of the length of time that a power outage lasts from the moment it begins until power is restored and it was measured by the No. of hours of power interruption experienced by the large hydropower plants per month.

ii. *Independent Variables*

Rainfall:

In this context, rainfall refers to the amount of precipitation in form of rain that is received throughout the country in mill meters (mm) per month.

Hydrology levels:

This refers to the amount of water available in Lake Victoria and used for electricity generation. It was measured in meters from reference point of 1122.892m.

System overload:

This occurs when the demand for electricity exceeds the supply capacity of the grid. It was measured using the number of system overload events experienced by the large experienced by the large hydropower plants per month.

Failed Equipment:

This refers to any malfunction or damaged equipment within the grid infrastructure such as transformers, power lines or circuit breakers. It was measured using the number of failed equipment recorded by the large hydropower plants per month.

Technical Faults:

They refer to any technical issue that occurs within the grid infrastructure such as faults in control systems, communication systems or protection systems. It was measured using the number of technical faults recorded by the large hydropower plants

Repair and maintenance costs:

The amount of money power utilities spend on maintaining and repairing the power grid and was measured using repair and maintenance costs incurred by the large hydropower plants per month.

System shutdowns:

These include unplanned shutdowns caused external or internal operations and planned shutdowns caused by planned operations. It was measured using the number of times the large hydropower plants experienced system shutdowns per month.

c) Estimation Model Procedure

One of the basic parameters that define the reliability of the power grid is the number of and length of time of power grid system failures (Tsimtsios & Safigianni, 2016). This paper sought to determine the effect of environmental factors on the reliability of generation grid electricity. Theoretically and empirically, grid reliability can be influenced by environmental factors (Alhelou *et al.,* 2019; Shewhart & Wilks 2021).

$$Reliability\ of\ Grid\ Electricity_t = \alpha + \beta_1 environmental\ factors_t + e_t \ldots\ldots \quad \text{Equation 1}$$

The study first carried out pre estimation tests on the data before deciding on which time series model to use for estimation. In order to observe the long term movement in the data this study used time series line plots. The time series line plots of the study variables are documented in the appendix section this paper. It is paramount to do unit root tests of all the variables in the model before estimating the model in order to avoid the problem of spurious results which emanate from estimation of non-stationary time series. Therefore the study carried unit root tests for stationarity using Augmented Dickey Fuller (ADF) (1979 and 1981) and (Phillips and Perron, 1986) tests to determine the order of integration of the variables in the model both in levels and in first difference. The results of the unit root test as shown in the appendix section, show that all the variables except hydrology levels, were stationary in levels. Hydrology levels became stationary after differencing it once. Therefore, since the variables had a mixture of both I (0) and I (1) orders of integration, it was possible to estimate the ARDL model for the generation subsystem.

To ascertain if the independent variables had a long run relationship with their dependent variables, the study carried out co-integration tests. The results for the cointegration test(s) for the are shown in the appendix section.

For the generation subsystem, the dependent variables are frequency of power outages (FOU_t) and duration of power outages $(DOU_{t)}$ and their lagged values were expressed as FOU_{t-1} and DOU_{t-1} for frequency of power outages and duration of power outages respectively. The explanatory variables in the model include; hydrology levels of lake Victoria (HL) and rainfall (RF). Their lagged values are expressed as HL_{t-1} and RF_{t-1}. This study controlled for system shutdowns (SH_t), maintenance and repair costs (MR_t), technical faults (TF_t), failed equipment (BE_t) and system overload (O_t). The lagged values of the control variables were expressed as; shutdowns (SH_{t-1}), maintenance and repair costs (MR_{t-1}), technical faults (TF_{t-1}), failed equipment (BE_{t-1}) and system overload (O_{t-1}), which have been documented as influencers of grid electricity reliability.

d) Econometric model Estimation for the study

According to the systems reliability theory Shewhart and Wilks (2021) and Ward (2013) grid electricity reliability is influenced by environmental factors such as hydrology levels and rainfall. Basing on such a background, the study therefore formulated the ARDL regression model (s) shown equations 2 and 3 for both frequency and duration of power outages;

$$\boldsymbol{FOU_t} = f\,(SH_t, MR_t, RF_t, HL_t, BE_t, TF_t, O_t) \ldots\ldots \text{Equation 2}$$

$$\boldsymbol{DOU_t} = f\,(SH_t, MR_t, RF_t, HL_t, BE_t, TF_t, O_t) \ldots\ldots \text{Equation 3}$$

Equation 4 is the ARDL estimation model, which was used to analyze the long term and short term relationship between the variables of the study plus the error correction term for the frequency of power outages.

$$\begin{aligned} lnFOU_t = {} & \beta_0 + \beta_1 lnFOU_{t-1} + \beta_2 ln\,SH_{t-1} + \beta_3 ln\,MR_{t-1} + \beta_4 ln\,RF_{t-1} + \beta_5 \Delta\,ln\,HL_{t-1} + +\beta_6 ln\,TF_{t-1} + \\ & \beta_7 ln\,BE_{t-1} + \beta_8 ln\,O_{t-1} + \textstyle\sum_{i=1}^{a} \beta_{9,i}\, lnFOU_{t-1} + \sum_{i=1}^{b} \beta_{10,i}\, ln\,SH_{t-i} + \sum_{i=1}^{c} \beta_{11,i} + ln\,MR_{t-i} + \sum_{i=1}^{d} \beta_{9,i}\, ln\,RF_{t-i} + \\ & + \textstyle\sum_{i=0}^{e} \beta_{10,i}\, \Delta\, ln\,HL_{t-0} + \sum_{i=0}^{f} \beta_{10,i}\, ln\,FT_{t-0} + \sum_{i=0}^{g} \beta_{10,i}\, ln\,BE_{t-0} + \sum_{i=0}^{h} \beta_{10,i}\, ln\,O_{t-0} + \\ & \cdots \ldots\ldots\ldots\ldots + \theta_6 ECM_{t-1} + e_t \ldots\ldots\ldots\ldots \quad \text{Equation 4} \end{aligned}$$

Relatedly, for duration of power outages the same steps were followed and the ARDL model was established as below in equation 5;

$$lnDOU_t = \beta_0 + \beta_1 lnDOU_{t-1} + \beta_2 ln\, SH_{t-1} + \beta_3 ln\, MR_{t-1} + \beta_4 ln\, RF_{t-1} + \beta_5 \Delta\, ln\, HL_{t-1} + +\beta_6 ln\, TF_{t-1} + \beta_7 ln\, BE_{t-1} + \beta_8 ln\, O_{t-1} + \sum_{i=1}^{a} \beta_{9,i}\, lnFOU_{t-1} + \sum_{i=1}^{b} \beta_{10,i}\, ln\, SH_{t-i} + \sum_{i=1}^{c} \beta_{11,i} + ln\, MR_{t-i} + \sum_{i=1}^{d} \beta_{9,i}\, ln\, RF_{t-i} + + \sum_{i=0}^{e} \beta_{10,i}\, \Delta\, ln\, HL_{t-0} + \sum_{i=0}^{f} \beta_{10,i}\, ln\, TF_{t-0} + \sum_{i=0}^{g} \beta_{10,i}\, ln\, BE_{t-0} + \sum_{i=0}^{h} \beta_{10,i}\, ln\, O_{t-0} + \cdots \ldots\ldots\ldots\ldots.. + \theta_6 ECM_{t-1} + \lambda_t \ldots\ldots\ldots\ldots \quad \text{Equation 5}$$

Where Δ was the first order differential operator, $\boldsymbol{\lambda_t}$ *and* $\boldsymbol{e_t}$ represent the white noise.

IV. Results of the Study

a) *Descriptive Statistics*

Table 1 presents the descriptive statistics of the study variables (dependent and independent) for the generation subsystem.

Table 1: Descriptive Statistics of Variables of the Study (N= 128)

Variable	Mean	Std. dev.	Min	Max	Skewness	Kurtosis
Maintenance and repair costs	408.01	651.29	54	3860	3.99	20.24
System shutdowns	21.86	18.18	1	118	2.08	9.46
Hydrology levels	12.174	0.47	11.31	13.4	-0.49	8.41
Rainfall	111.65	52.59	32.90	247.71	0.03	2.25
Technical Faults	53.57	39.48	6	248	1.85	7.58
Failed Equipment	2.81	3.42	0	21	2.39	10.67
Frequency of Outages	230.08	74.36	92	643	2.52	13.45
Duration of Outages	4757.02	1351.44	17.38	5976.38	0.57	7.42

Source: STATA Software 17 outputs.

All the large hydropower plants combined experienced an average of 230 power interruptions per month. The average duration of power interruption was 4757 h per month. On average, the water levels were 12.17 m above 1122.892 m in reference to Mombasa from Jinja. On average, technical faults occurred 54 times per month, whereas grid components failed on average three times per month. The average amount of rainfall received throughout the country is 11.65 mm per month. The generation grid spends an average of 408 million (Uganda Shillings) on maintaining and repairing the grid. On average, system shutdowns took place 21 times per month.

V. Results of the Study

a) *Estimation results of the short term and long term ARDL model for the frequency and duration of power outages*

Table 2 shows the estimation results on the effect of the effect of hydrology levels of lake Victoria and rainfall on both the frequency and duration of power outages on the generation subsystem in both the short and long run. The optimal lag order of each variable in the models was identified using HQIC, AIC and SBIC. Therefore, the ARDL (1, 4, 3, 1, 3, 2, 2, 2) was identified to be the most appropriate. The coefficients together with their respective probabilities are displayed below.

Table 2: The Estimation Results of the Long Term and Short Term Model of ARDL for the Frequency and Duration of Power Outages.

		Frequency of power outages		Duration of power outages	
Models	Variable	Coefficient	P-value	Coefficient	P-value
Long term model	In system shutdowns	0.1720	0.010	0.1201	0.273
	In maintenance and repair costs	-0.0348	0.330	-0.7555	0.011
	In rainfall	0.1949	0.009	0.1125	0.326
	D. Hydrology levels	-0.9151	0.043	-0.4486	0.518
	In technical faults	0.2080	0.002	-0.0141	0.907
	In failed equipment	-0.0125	0.833	0.2102	0.066
	System overload	0.0442	0.077	-0.1001	0.809
	C	3.004	0.000	4.8252	0.001
Short term model	In system shutdowns D1. LD. L2D. L3D.	0.0077 -0.0309 -0.5952 -0.0901	0.895 0.526 0.140 0.004	-0.0003 -0.0060 -0.0362 -0.0430	0.996 0.920 0.448 0.209
	In maintenance and repair costs D1. LD. L2D.	-0.0424 -0.0046 -0.0248	0.347 0.906 0.523	0.0572 0.0104 0.0608	0.266 0.822 0.160
	In rainfall D1.	-0.0951	0.065	-0.0194	0.724
	D. Hydrology levels D1. LD. L2D.	0.7626 0.1913 0.0448	0.019 0.276 0.707	0.3039 0.3649 0.0074	0.405 0.070 0.958
	In failed equipment D1. LD.	-0.0207 0.1018	0.642 0.162	-0.1125 0.0527	0.044 0.149
	In technical faults D1. LD.	-0.0231 0.1018	0.754 0.108	0.0863 0.1376	0.228 0.844
	System overload D1. LD.	-0.0020 -0.0025	0.911 0.839	0.0306 0.0070	0.128 0.617
	ECM	-0.8679	0.000	-0.5672	0.002

Source: STATA Software 17 outputs

In table 2, the study found that a unit increase in meters in the hydrology levels of Lake Victoria led to 91.5 percent (significant) decrease in the frequency of generation grid power interruptions hence increasing grid electricity reliability. The coefficient of hydrology levels in the long run implies that high hydrology levels improve grid reliability to large extent. In the short run however, hydrology levels of lake Victoria were negatively associated with grid electricity reliability in the long run because a unit increase in meters in the hydrology levels of Lake Victoria led to 76 percent (significant) increase in the frequency of generation grid power interruptions hence compromising grid electricity reliability. This implies that the increases in the water levels of lake Victoria were not sufficient enough for power generation purposes.

In terms of duration of power outages, a unit increase in meters in the hydrology levels of Lake Victoria in the long run, led to 44 percent (not significant) decrease in the duration of power outages, hence improving grid electricity reliability. In the short run, however, a unit increase in meters in the hydrology levels of Lake Victoria led to 36 percent (significant) increase in the duration of power outages. This implies that the increases in the water levels of lake Victoria were not sufficient enough for power generation purposes.

Therefore the H1 was supported in both in terms of frequency of power outages in both the long and short runs. In terms of duration of power outages, H1 was supported only in the short run.

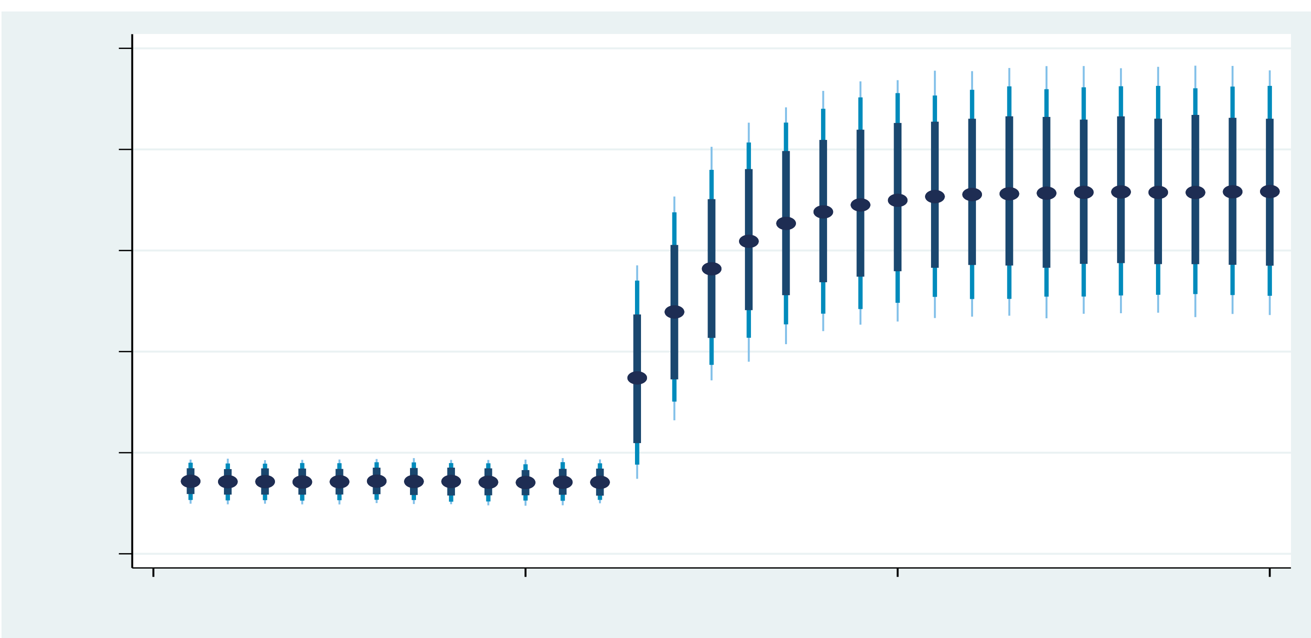
In normal practice, in Uganda, the River Nile Basin management, with the permission of the Directorate Water Resources under the Ministry of water and Environment, regulates the amount of water that each generator can draw from Lake Victoria for power generation purposes. This is referred to as the flow rate usage. In the event that the flow rate usage is Q = 1000cc/ per second, this implies that a generator can only supply 4173.6 MWh an equivalent of 17 MWh. This could sometimes be below the capacity of the generator. This poses a big challenge in the face of growing demand for energy amidst climate change shocks especially in the future. Bujagali, Owen falls and Kiira dams all experienced low hydrology levels between 2012 and 2022.

In terms of frequency of power outages, a unit increase in the percentage of rainfall in the generation subsystem led to 19.5 percent (significant) increase in the frequency of generation grid power interruptions hence reducing grid electricity reliability in the long run. In the short run, rainfall significantly reduced power interruptions by 9 percent. This implies that rainfall did not disrupt the power generation activities at the hydro power plants in the short run.

In terms of duration of power outages, the study found out that a unit increase in the percentage of rainfall in the generation subsystem led to 11.3 percent (not significant) increase in the duration of generation grid power interruptions, hence reducing grid electricity reliability in the long run. In the short run, a unit increase in the percentage of rainfall in the generation subsystem led to 1.9 percent (not significant) decrease in the duration of generation grid power interruptions, hence improving grid electricity reliability. The coefficients of rainfall in both the long and short runs imply that rainfall, did not significantly affect the duration of power interruptions in the generation of hydropower. Therefore the H2 was supported in terms of frequency of power outages both the long and short runs. In terms of duration of power outages H2 was not supported.

b) *Dynamic ARDL Simulations for the Frequency of Power Outages Due to Changes in Environmental Variables.*

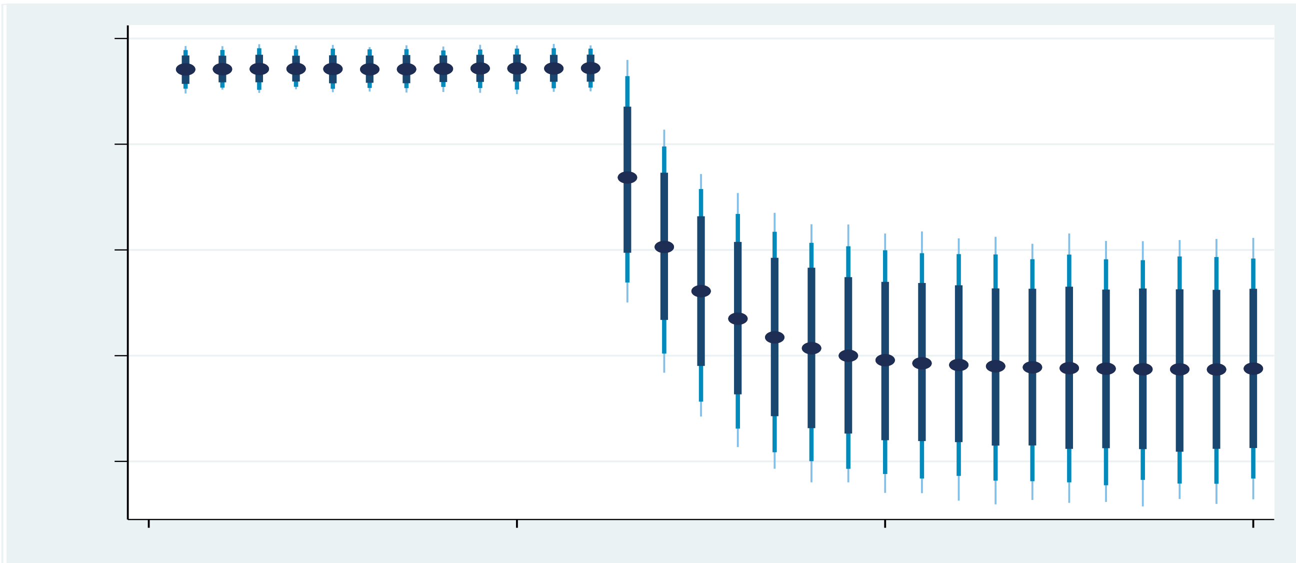
This study also carried out dynamic ARDL simulations to capture future shocks in the frequency of power outage due to changes in both hydrology levels of lake Victoria of in the generation subsystem. The dynamic ARDL simulations revealed that a 10 percent shock in predicted decrease in hydrology levels of lake Victoria may increase the frequency of power outages in the short only at 75 percent, 90 percent and 95 percent confidence levels as shown in figure 1.



Source: STATA Software 17 outputs

Figure 1: Dynamic ARDL Simulations for Frequency of Power Outages in the Generation Subsystem Due to -10% Shock in Hydrology Levels

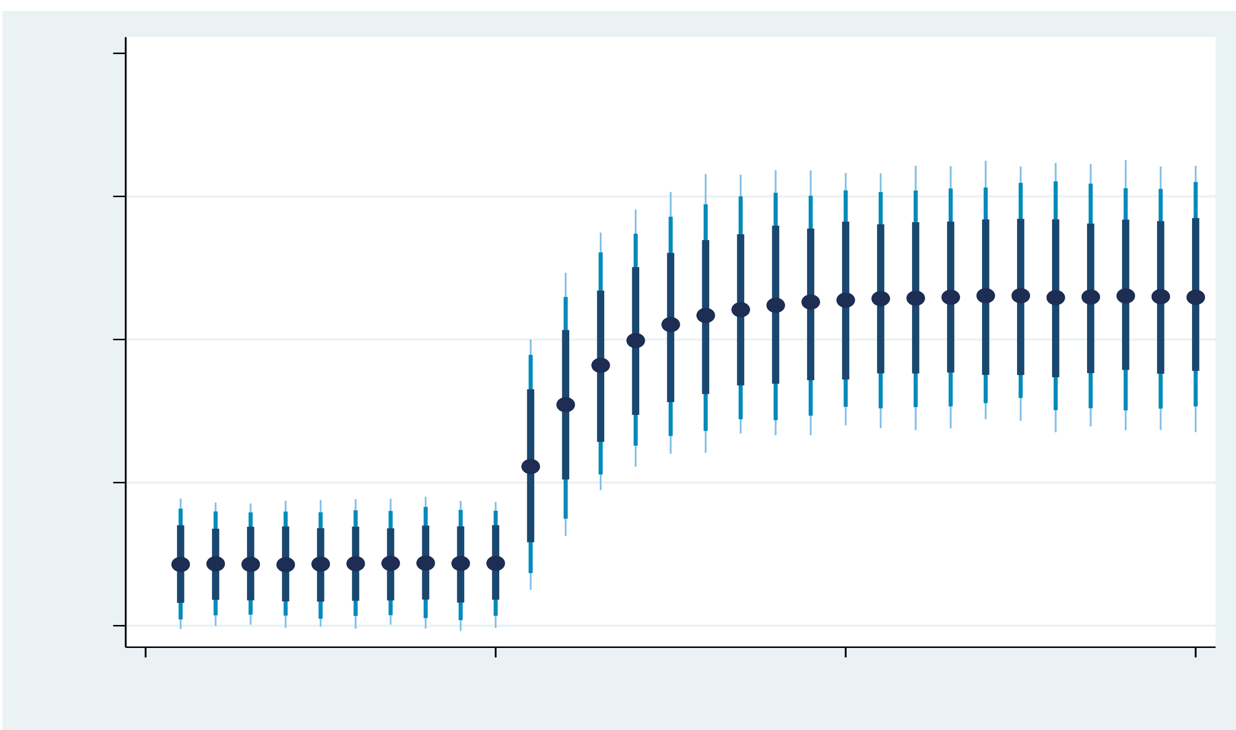
On the other hand, the dynamic ARDL simulations revealed that a 10 percent shock in predicted increase in hydrology levels of lake Victoria may reduce in the frequency of power outages in only the short run only at 75 percent, 90 percent and 95 percent confidence levels as shown in figure 2.



Source: STATA Software 17 outputs

Figure 2: Dynamic ARDL Simulations for Frequency of Power Outages in the Generation Subsystem Due to 10% Shock in Hydrology Levels

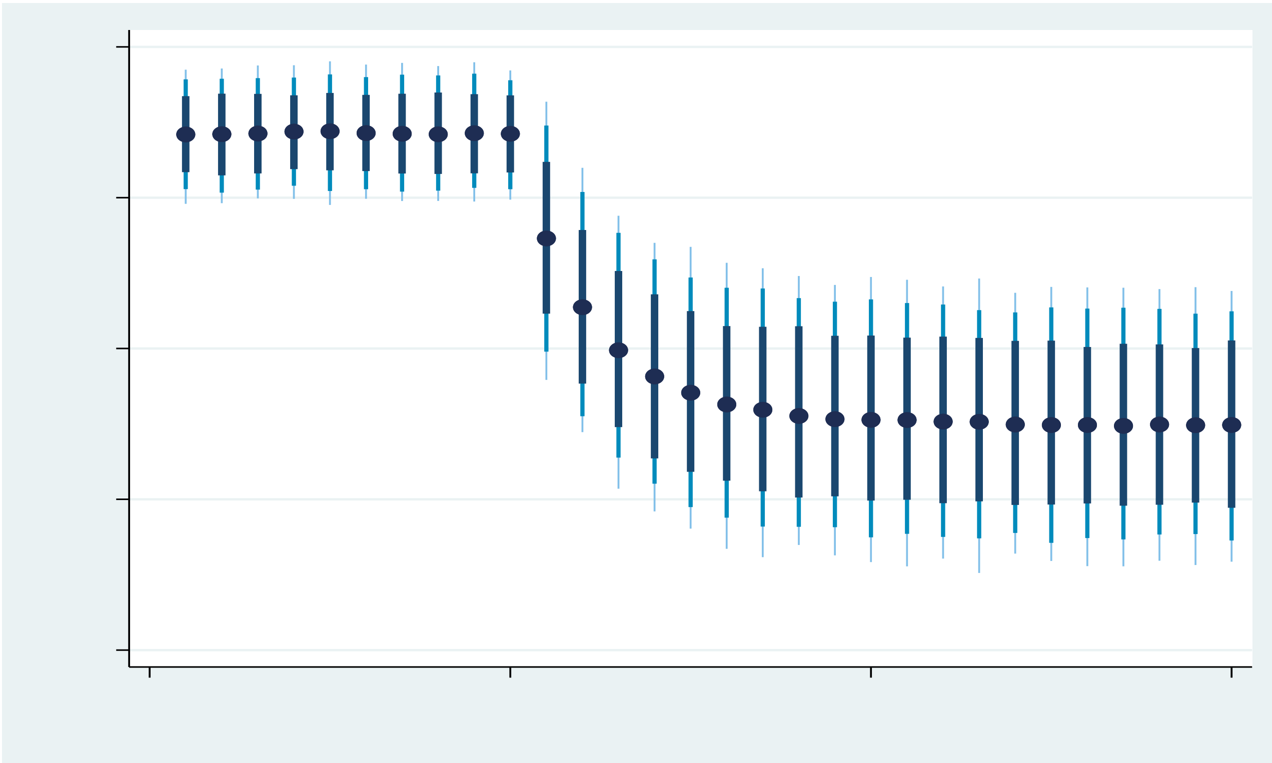
The dynamic ARDL simulations revealed that a 10 percent shock in predicted increase in rainfall may increase the frequency of power outages in the short only at 75 percent, 90 percent and 95 percent confidence levels as shown in figure3.



Source: STATA Software 17 outputs

Figure 3: Dynamic ARDL Simulations for Frequency of Power Outages in the Generation Subsystem Due to 10 Percent Shock in Rainfall

The dynamic ARDL simulations revealed that a 10 percent shock in predicted decrease in rainfall may reduce the frequency of power outages in the short only at 75 percent, 90 percent and 95 percent confidence levels as shown in figure 4.

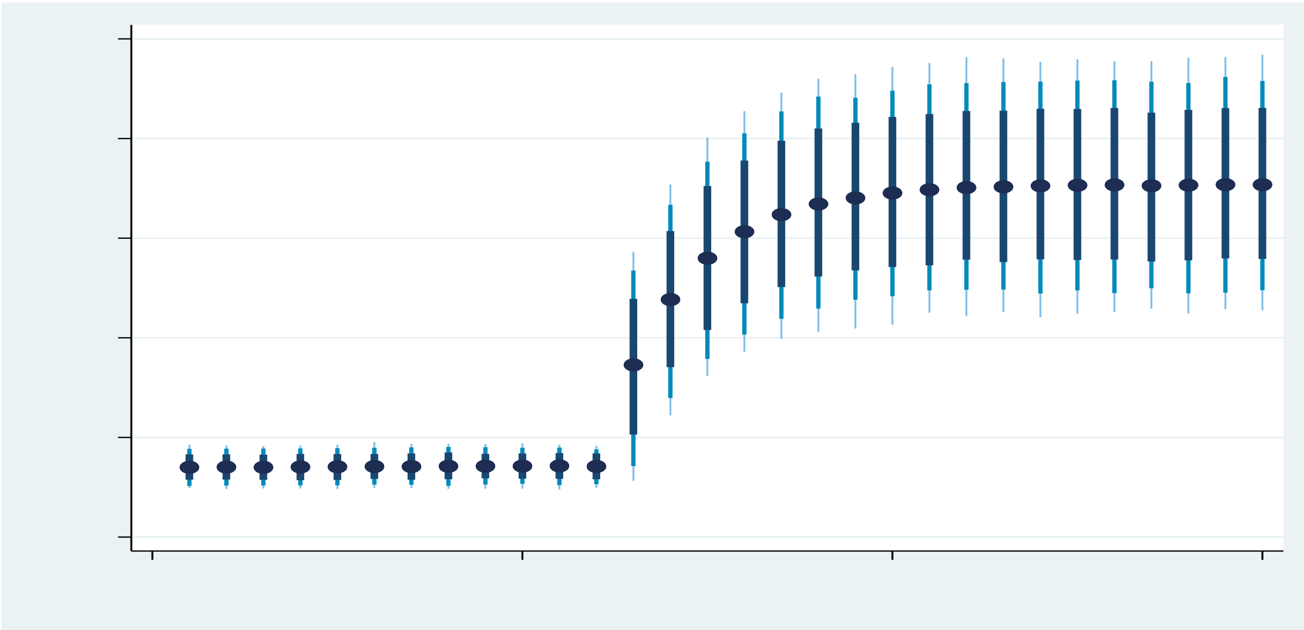


Source: STATA Software 17 outputs

Figure 4: Dynamic ARDL Simulations for Frequency of Power Outages in the Generation Subsystem Due to 10 Percent Shock in Rainfall

c) Dynamic ARDL Simulations for the Frequency of Power Outages Due to Changes in Environmental Variables

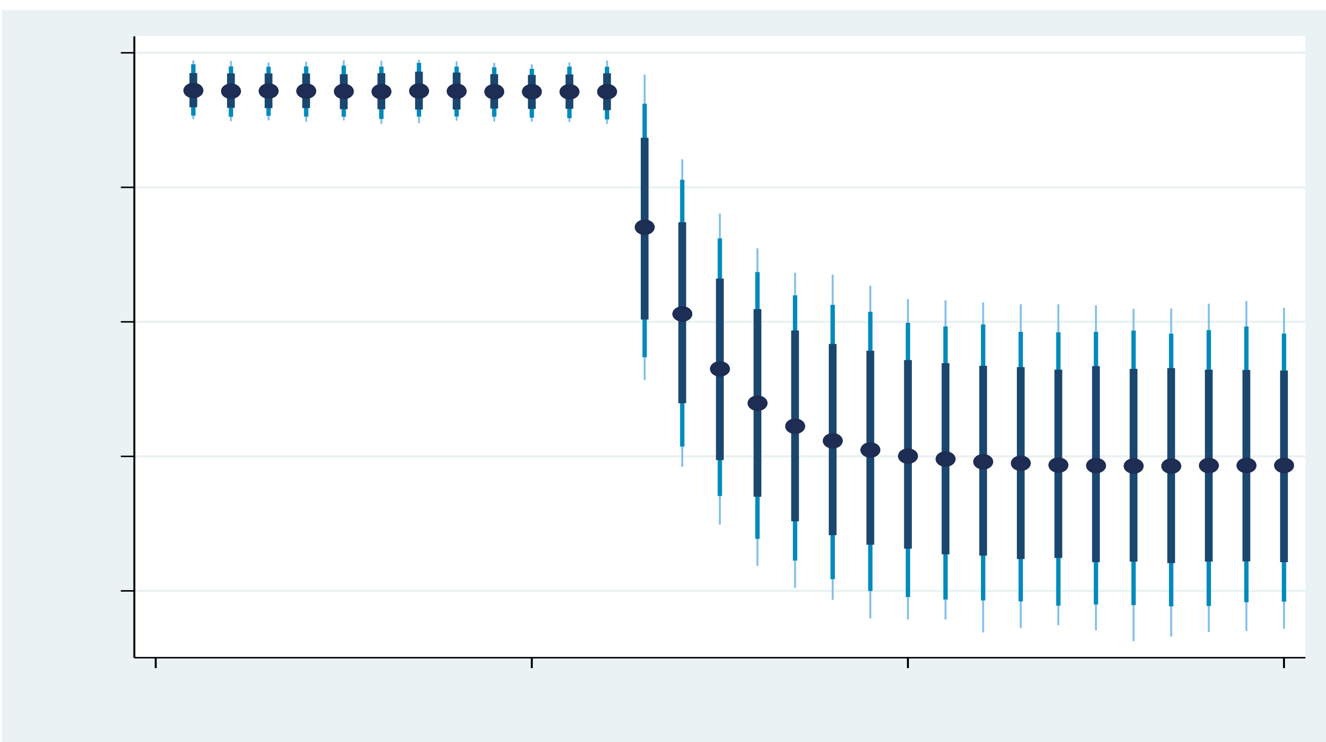
This study also carried out dynamic ARDL simulations to capture future shocks in the duration of power outage due to future changes in both hydrology levels of lake Victoria and rainfall in the generation subsystem. The dynamic ARDL simulations revealed that a 10 percent shock in predicted decrease in hydrology levels will reduce the duration of power outages in the short only at 75 percent, 90 percent and 95 percent confidence levels in figure 5.



Source: STATA Software 17 outputs

Figure 5: Dynamic ARDL Simulations for Duration of Power Outages in the Generation Subsystem Due to -10% Shock in Hydrology Levels

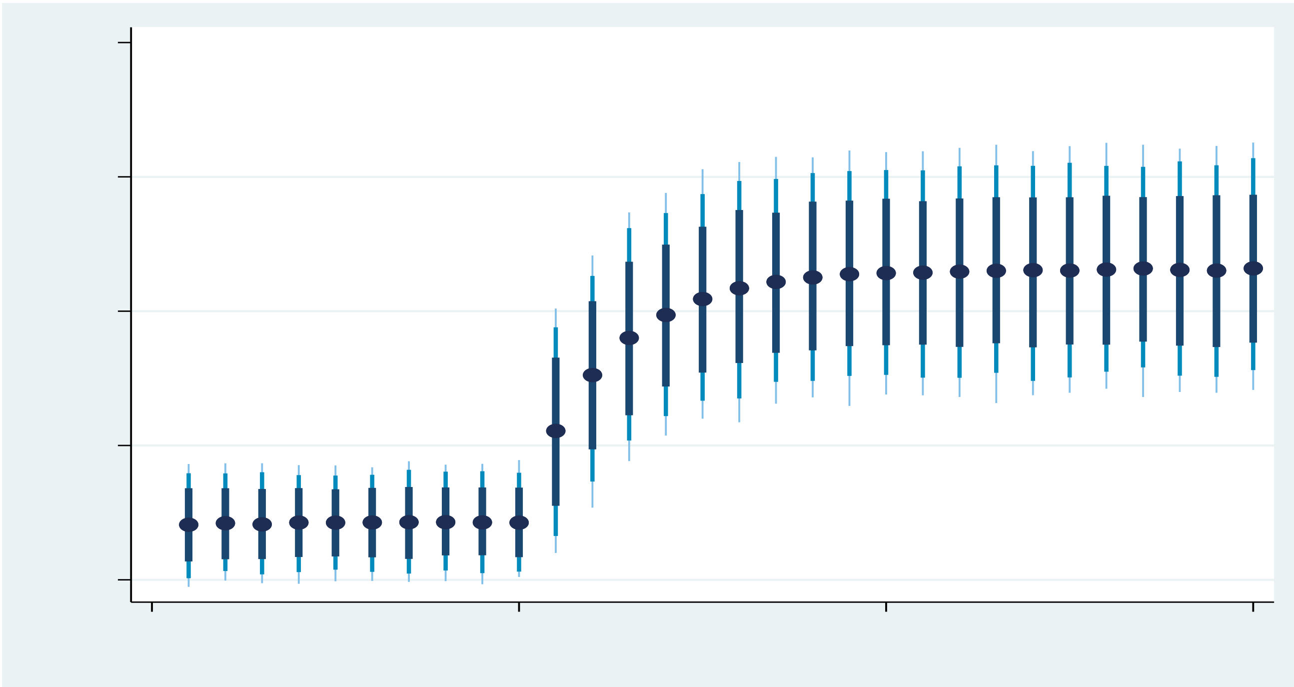
Similarly, the dynamic ARDL simulations revealed that a 10 percent shock in predicted increase in hydrology levels of lake Victoria may decrease the duration of power outages in the short run only 75 percent, 90 percent and 95 percent confidence levels as shown in figure 6.



Source: STATA Software 17 outputs

Figure 6: Dynamic ARDL Simulations for Duration of Power Outages in the Generation Subsystem Due to 10% Shock in Hydrology Levels

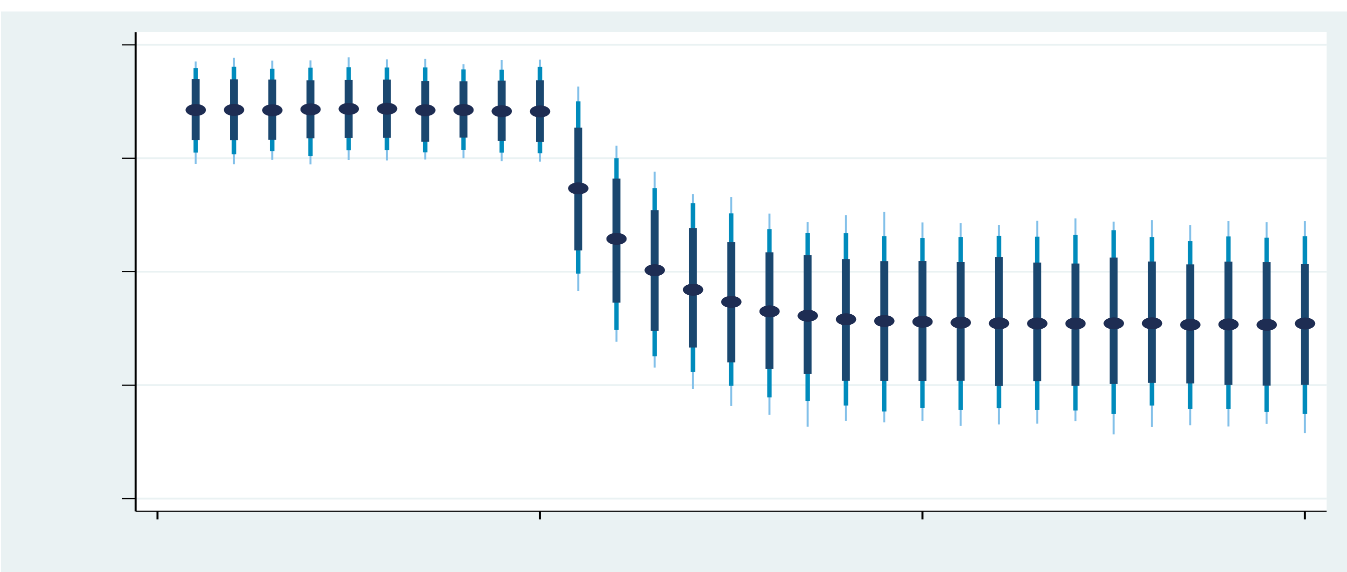
The dynamic ARDL simulations further revealed that a 10 percent shock in predicted increase in rainfall may increase the duration of power outages in the short run only 75 percent, 90 percent and 95 percent confidence levels as shown in figure 7.



Source: STATA Software 17 outputs

Figure 7: Dynamic ARDL simulations for duration of power outages in the generation subsystem due to 10 percent shock in rainfall

On the other hand, the dynamic ARDL simulations further revealed that a 10 percent shock in predicted decrease in rainfall may reduce the duration of power outages in the short run only 75 percent, 90 percent and 95 percent confidence levels as shown in figure 8.



Source: STATA Software 17 outputs

Figure 8: Dynamic ARDL Simulations for Duration of Power Outages in the Generation Subsystem Due to 10% Shock in Rainfall

d) 4.2 Validity of the Estimated Models

The study first carried out pre estimation tests on the data before deciding on which time series model to use for estimation. The time series line plots of the study variables to observe the long term movement in the data were carried out by the study. Unit root and co integration tests of all the variables in the model were also carried out. The study also carried out some post estimation tests including Breusch- Godfrey serial correlation test, Ramsey reset model specification test, Cameron and Trivedi's decomposition of IM test for heteroskedasticity test and the multicollinearity test, to ensure the validity of the estimated models. The results of the tests presented in the appendix show that the models ware robust.

VI. Discussion of Results

The outcomes from the model estimation reveal that in the long run, both rainfall and hydrology levels of Lake Victoria, have statistically significant effect on both the frequency and duration of power outages. Hydrology levels of Lake Victoria had a positive and statistically significant effect on the frequency of power outages in the generation subsystem in the long run. This implies that high hydrology levels of Lake Victoria will improve grid electricity in the generation subsystem in the long run through reduced frequency of power outages. However, hydrology levels of lake Victoria in the short run, had a negative effect on the frequency of grid electricity reliability in the generation subsystem. This implies that, despite the increase of hydrology levels of lake Victoria, power outages will still take place in the short run. This could be because this increase in hydrology levels will not besufficient for the power generation purposes as earlier pointed out.

In terms of duration of power interruptions, hydrology levels of lake Victoria significantly affected the duration of power outages in only the short run. This implies that the hydrology levels of Lake Victoria have not been sufficient enough for power generation activities in the recent time periods and therefore this led to long hours of power outages. This study notes that this challenge did not spill over to the later time periods because the duration of this duration of the power outages was insignificant in the long run. The study notes that the effect of hydrology levels of Lake Victoria no the generation grid reliability in terms of both frequency and duration of power outges have not been discussed before in empirical literature.

This finding is in line with the theory of system reliability which states that environmental factors influence the reliability of a system in one or the other, by leading to either system failures or system faults (Shewhart & Wilks, 2021). Other studies also agree with the findings of this study, which point out that Uganda's power sector is sensitive to water fluctuations from climatic change effects and this has caused unreliable power supply on the grid network (ERA, 2019; Wabukala et al., 2021) although these studies do not explain this fluctuation in terms of both frequency and duration of power outages.

Rainfall had a statistically significant (at 1 percent level of significance) positive effect on the frequency of power interruptions in the long run. This implies that rainfall will interrupt negatively the future power generating activities for the hydropower plants because by increasing the frequency of power outages. In the short run, rainfall has a negative effect on the frequency of power interruptions (at 10 percent level of significance). This implies that rainfall will not significantly interrupt power generating activities for the hydropower plants, despite an increase in the rainfall intensity.

In terms of duration of power interruptions, rainfall did not significantly affect the duration of power outages in both short and long run. This implies that rainfall leads to power outages on the generation grid but not for a long duration. The power generation activities quickly resume after rainfall events.

This result is consistent with the works of (Ward, 2013) who points out that the effects of weather on power grid systems and revealed that rainfall has an effect on grid systems, hence influencing grid electricity reliability. Additionally, (Ward, 2013) adds that heavy rain is normally associated with strong winds or lightning and concludes that faults brought about by normal weather usually have no significant effect on the supply of electricity to the customers. However (Ward, 2013) studied the distribution subsystem while this study looked at the generation subsystem. In addition, Davidson *et al.,* (2003) also found out that rainfall led to power grid outages while Kabir *et al.,* (2019) in their study also document rainfall as one of the influences of grid electricity reliability. However, these studies were also done in the distribution subsystem.

This results of this study are supported by the systems reliability theory which states that environmental factors can influence the reliability of a system hence resulting in either system interruptions (Shewhart & Wilks, 2021). In the past, rainfall has also been associated with floods (Ward, 2013) and floating vegetation (UEGCL, 2020) which are common features of Lake Victoria usually and have in the past disrupted electricity generation activities hence leading to power outages.

a) Conclusion and Policy Recommendation

This study investigated the environmental factors that influence grid reliability in the generation subsystem. The study focused on the large hydropower plants that are connected to the national grid network that is kiira, Owenfall, Bujagali and Isimba hydropower plants. The study estimated an ARDL to model secondary time series data from 2012 to 2022 and found out that;

1. Rainfall increased frequency of power interruptions in the generation subsystem in both the short and long runs.
2. Rainfall did not increase duration of power interruptions in the generation subsystem in both the short and long runs.
3. Hydrology levels of Lake Victoria reduced frequency of power interruptions in the generation subsystem in the long run, but increased frequency of power interruptions in the generation subsystem in the short.
4. Hydrology levels of Lake Victoria significantly increased the duration of power interruptions in the generation subsystem in only the short run.

Our findings contribute to literature in the following ways. a). Analysing the effect of hydrology levels of Lake Victoria and rainfall on the generation grid electricity reliability in the Ugandan context b). The use of the systems reliability theory to analyse the effect of environmental factors on grid electricity reliability c). Using the ARDL model to estimate the short and long run effect of hydrology levels of Lake Victoria rainfallon both the frequency and duration of power outages .

Our findings imply that government should devise policies that increase grid electricity reliability in Uganda at the generation subsystem. We therefore suggest in order to reduce power interruptions in the generation subsystem, the government should invest in also strengthen policy in line with climate related action. This will help reduce the effect of environmental factors on grid electricity reliability. Hydropower generating firms are stakeholders of water resources and should participate in protecting them the environment if we are to have sustainable water resources for future use. Government needs to sensitize both the water users as well as the water source stakeholders of the need to appreciate the risks of poorly managed or neglected water sources that result in the compromised quality and quantity of water supply. This will increase the necessity to protect and preserve water sources in order to solve the ever-increasing challenges of sustaining acceptable supply of clean water required for among others the generation of grid power.

Government should also mobilise the various hydropower generating firms to contribute in all spheres towards the management of water sources. This will create a sense of ownership and of the water resource by its users and this could increase the protection of the water resources. We suggest stringent punishments for organisations and individuals who misuse the water resources. This will go an extra mile in the protection of water resources thus ensuring quality and quantity for hydropower production and also other uses.

In addition, we also suggest investing in robust power generating infrastructure as an alternative way of adapting to the changing environmental conditions as well as considering having alternative energy sources such as solar and wind onto the grid to diversify the energy mix and reduce dependence on hydropower.

b) Areas for Further Research

This study focused rainfall and hydrology levels of Lake Victoria as factors that influence generation grid electricity reliability. However, there could be more environmental factors that influence grid electricity reliability. Future research in Uganda should investigate further the effect of floods and floating vegetation that influence grid electricity reliability. In addition further research needs to investigate the effect of the environmental factors on each of the hydro power plants for better future policy direction

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Appendix

For the Frequency of power outages

Validity of the estimated model

The study carried out some post estimation tests to ensure the validity of the model.

a) *Serial Correlation Test*

The study tested for serial correlation at 5 lags as shown in table A1 and concluded that the errors were not serially correlated.

Table A1: Breusch-Godfrey Test for Serial Correlation

Lags(p)	Chi2	Degrees of Freedom	Prob> chi2
5	14.374	5	0.0134

The results show that the p value (0.0134) is greater than 0.01 implying that we fail to reject the null hypothesis and conclude that there is no serial correlation at 1 percent level of significance.

b) *Model Specification Test*

The results in table A2 show that the p value (0.0752) is greater than 0.05 implying that we fail to reject the null hypothesis and conclude that the model is correctly specified.

Table A2: Ramsey Reset Test for Model Specification

Test statistic	Degrees of Freedom	P–Value	Result
2.58	3	0.0752	

c) *Heteroskedasticity Test*

The results in table A3 show that the p value (0.4365) is greater than 0.05 implying that we fail to reject the null hypothesis and conclude that homoscedasticity is present.

Table A3. Cameron and Trivedi's Decomposition of IM test

Source	Chi	Degrees of Freedom	P-value
Heteroskedasticity	55.00	54	0.4365
Skewness	32.99	25	0.1313
Kurtosis	0.00	1	0.9766
Total	87.99		0.2533

d) *Multicollinearity Test*

The results in table A4show that the mean VIF value (3.26) is less than 5 implying that the variables do not have multicollinearity. The study concludes that there is a moderate level of correlation among the independent variables of the study.

Table A4: VIF test for multicollinearity

Variable	VIF	1/VIF
In maintenance and repair cost L1.	8.59	0.11
In frequency of power outages L1.	8.28	0.12
In maintenance and repair cost L2.	6.94 5.93	0.14 0.16
In Technical faults L1.	5.39	0.18
In maintenance and repair cost L3.	4.36	0.22
In system shutdowns L1.	3.72 3.65	0.26 0.27
In Technical faults L2.	3.09	0.32
In Rainfall L1.	2.52	0.39
In system shutdowns L3.	2.29	0.43
In Technical faults	2.25	0.44
Hydrology levels L3.	2.21	0.45
In system shutdowns L2.	2.17	0.46
In Rainfall	2.08	0.48
System overload	2.07	0.48
Hydrology levels	1.99	0.50
In Failed equipment	1.95	0.51
Hydrology levels L1.	1.94	0.51
In System overload L1.	1.90	0.52
Hydrology levels L2.	1.78	0.56
In Failed equipment L2.	1.75	0.57

In system shutdowns L4.	1.65	0.60
In Failed equipment L1.	1.64	0.60
System overload L2.	1.48	0.67
Mean VIF	3.26	

For the Duration of Power Outages

Validity of the Estimated Model

The study carried out some post estimation tests to ensure the validity of the model.

a) Serial correlationtest

The study tested for serial correlation at 4 lags as shown in table A5 and concluded that the errors were not serially correlated.

Table A6: Breusch- Godfrey Test for Serial Correlation

Lags(p)	Chi2	Df	prob> chi2
4	7.810	4	0.0988

The results show that the p value (0.0988) is greater than 0.05 implying that we fail to reject the null hypothesis and conclude that there is no serial correlation at five percent level of significance.

b) Model Specification Test

The results in table A6 show that the p value (0.0054) is less than 0.05 implying that we reject the null hypothesis and conclude that model could be having some missing variables.

Table A6: Ramsey Reset Test for Model Specification

Test statistic	Degrees of Freedom	P -Value	Result
5.33	3	0.0054	

c) Heteroscedasticity Test

The results in table A7show that the p value (0.4365) is greater than 0.05 implying that we fail to reject the null hypothesis and conclude that homoscedasticity is present.

Table A7: Cameron and Trivedi's Decomposition of IM Test

Source	Chi	Degrees of Freedom	P-value
Heteroscedasticity	55.00	54	0.4365
Skewness	25.06	25	0.4592
Kurtosis	0.30	1	0.5859
Total	80.35	80	0.4678

d) Multicollinearity Test

The results in table A8 show that the mean VIF value (2.98) is less than 5 implying that the variables do not have multicollinearity. The study concludes that there is a moderate level of correlation among the independent variables of the study.

Table A8: VIF Test for Multicollinearity

Variable	VIF	1/VIF
In maintenance and repair cost L1. L2.	8.75 6.82 6.11	0.11 0.14 0.16
In Technical faults L1.	4.25	0.23
In maintenance and repair cost L3.	4.13	0.24
In Duration of outages L1.	3.65	0.27
In system shutdowns	3.10	0.32
In Technical faults L2.	3.08	0.32
In system shutdowns L1.	2.44	0.40
D. Hydrology levels L3.	2.40	0.41
In In Rainfall L1.	2.39	0.41
In system shutdowns L3.	2.34	0.41
In Technical faults	2.22	0.44
In system shutdowns L2.	2.19	0.45
System overload	2.14	0.46
D. Hydrology levels L1.	2.07	0.48
In Rainfall	2.05	0.48
In Failed equipment L2.	1.92	0.48
D. Hydrology levels	1.87	0.52
System overload L1.	1.85	0.56
In system shutdowns L4.	1.75	0.57
In Failed equipment L1.	1.75	0.60
D. Hydrology levels L2.	1.48	0.60
System overload L2.	1.40	0.67
Mean VIF	2.98	

Time Series Plots for the Independent Variables

Source: *STATA Software 17 outputs*

Figure 9: Time Series Line Plots Independent Variables (Generation Subsystem)

Table 5: Results for the Unit Root Test for the Study Variables

Variable	Test statistic	1% critical value	5% critical value	10% Critical value	P-value
Frequency of outages Dickey fuller Phillips Perrone	-4.643 -4.635	-3.502 -3.501	-2.888 -2.888	-2.578 -2.578	0.0001 0.0001
Duration of outages Dickey fuller Phillips Perrone	-4.280 -5.253	-3.502 -3.501	-2.888 -2.888	-2.578 -2.578	0.0005 0.0000
System shutdowns Dickey fuller Phillips Perrone	-4.231 -6.393	-3.502 -3.501	-2.888 -2.888	-2.578 -2.578	0.0006 0.0000
Maintenance and repair costs Dickey fuller Phillips Perrone	-4.759 -3.952	-3.502 -3.501	-2.888 -2.888	-2.578 -2.578	0.0001 0.4592
Rainfall Dickey fuller Phillips Perrone	-9.819 -6.687	-3.502 -3.501	-2.888 -2.888	-2.578 -2.578	0.0000 0.0000
Hydrology levels Dickey fuller Phillips Perrone	-2.406 -2.955	-4.032 -3.501	-3.447 -2.888	-3.147 -2.578	0.3765 0.000
Technical faults Dickey fuller Phillips Perrone	-5.301 -5.732	-3.502 -3.502	-2.888 -2.888	-2.578 -2.578	0.000 0.0000
Failed equipment Dickey fuller Phillips Perrone	-4.823 -9.011	-3.502 -3.501	-2.888 -2.888	-2.578 -2.578	0.0000 0.0000
System overload Dickey fuller Phillips Perrone	-5.610 -9.520	-3.502 -3.501	-2.888 -2.888	-2.578 -2.578	0.0000 0.0000

Source: STATA Software 17 outputs

Co-integration test results (Frequency of outages)

Table 2: Pesaran, Shin, and Smith (2001) Bounds Test for Cointegration

Statistics		10%		5%		1%		P-value	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(0)
F	5.183	2.03	3.13	2.32	3.50	2.96	4.26	0.0000	0.0000
t	-4.878	-2.57	-4.23	-2.86	-4.57	-3.45	-5.19	0.0000	0.0000

Co-integration test results (Duration of outages)

Table 3: Pesaran, Shin, and Smith (2001) Bounds Test for Cointegration

Statistics		10%		5%		1%		P-value	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(0)
F	2.899	2.03	3.13	2.32	3.50	2.96	4.26	0.0000	0.0000
t	-3.394	-2.57	-4.23	-2.86	-4.57	-3.45	-5.19	0.0000	0.0000

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j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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